Water Quality Criteria for Agricultural Supply

Introduction and Approach

The CALFED program was created to address a number of environmental, water supply, water quality, and other challenges facing California's San Joaquin and Sacramento river Delta. The location of the Delta is shown on Figure 1, and a larger scale map of the Delta is provided in Figure 2.

In August, 1996, during the initial period of Phase 2 of CALFED, three technical subteams were convened to develop basic water quality information to guide refinement of the water quality component. This report presents the findings of the Agricultural Water Quality Subteam.

The approach by each of the subteams is shown in Figure 3, and consisted of the following steps:

- Identify water quality parameters that are of concern to agriculture
- Document the role of each parameter in agriculture
- Define the major linkages of each parameter with key aspects of land and water management
- Define the geographic relationships of sensitivity to the parameter
- Define temporal relationships of sensitivity to the parameter
- Define ranges of the parameter that are favorable for agricultural water use (referred to as agricultural water quality criteria)
- Summarize pertinent monitoring data for the parameters at geographically significant points

The sections of this report, then, document each of these steps.

The subteam was convened from a water user perspective, so that agriculture, along with other water use sectors, could define its water quality needs for inclusion among measurement criteria for CALFED activities. Therefore, the work focused on the quality of agricultural (primarily irrigation) water

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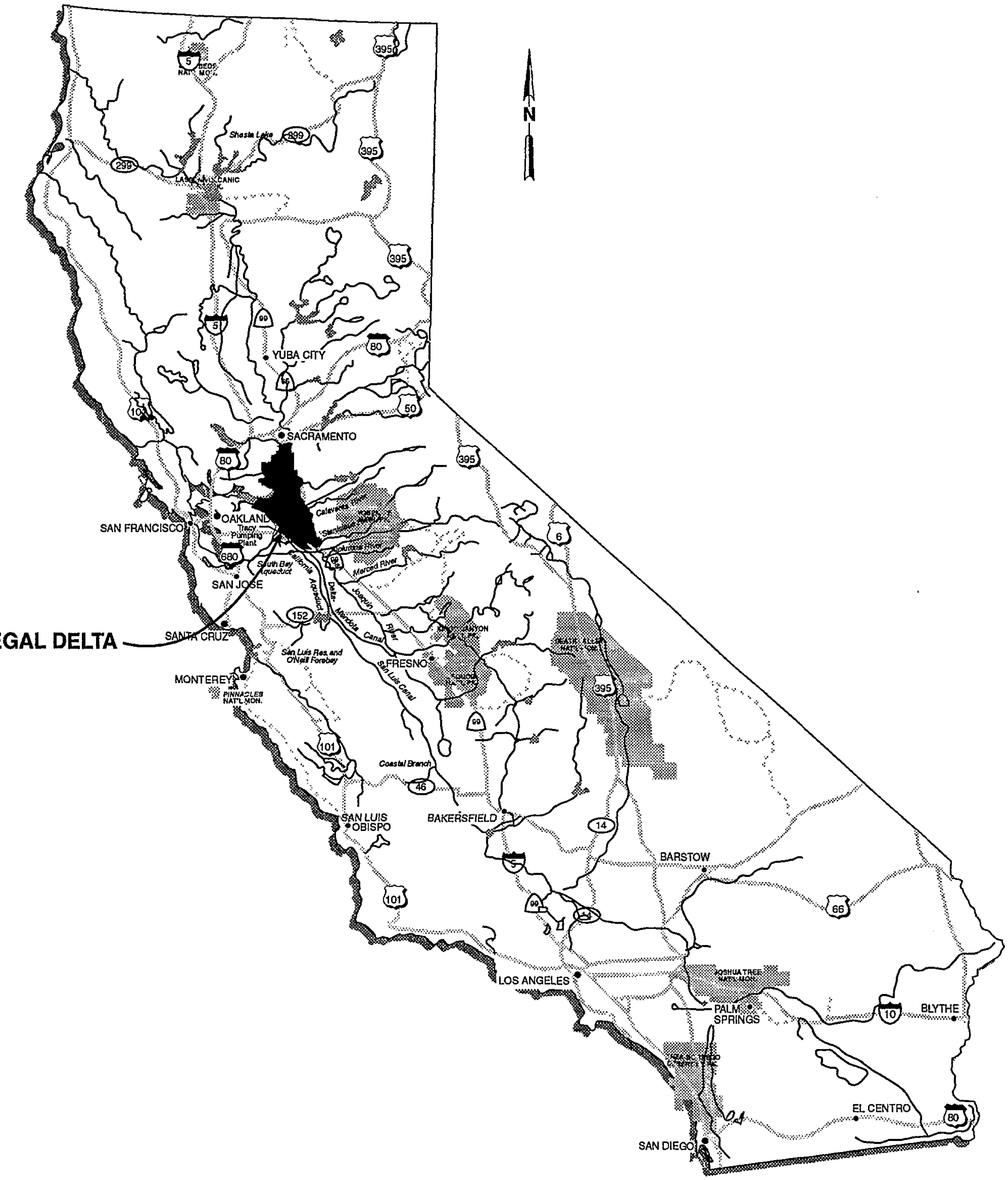

LEGEND

Major Central Valley Rivers and Associated Reservoirs

Other Rivers and Reservoirs

Major Conveyance Facilities

FIGURE 1
PROJECT LOCATION MAP
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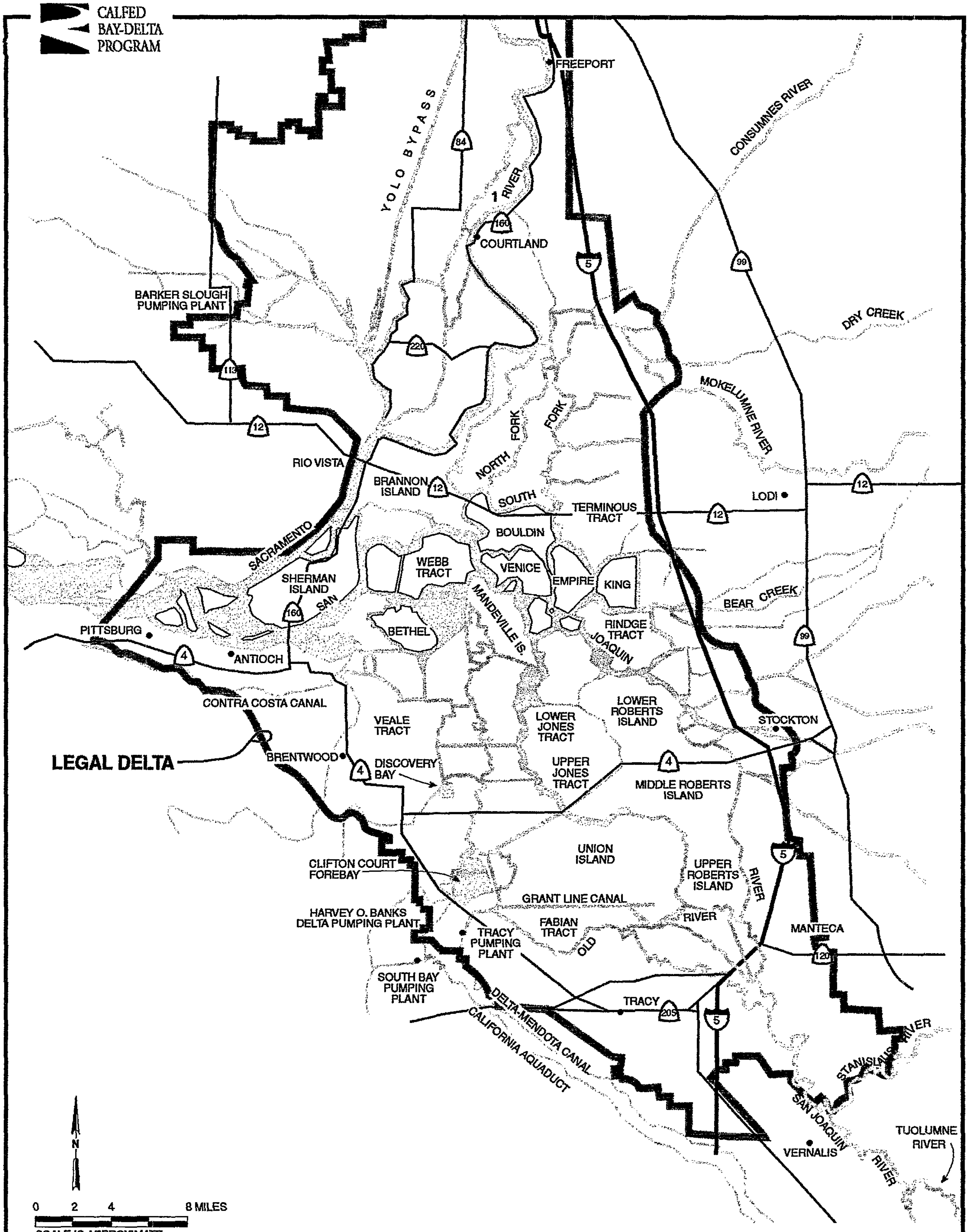

SOURCE:
SACRAMENTO-SAN JOAQUIN
DELTA ATLAS
DWR, 1995

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FIGURE 2
DELTA LOCATION MAP INCLUDING WATERWAYS AND ROADS
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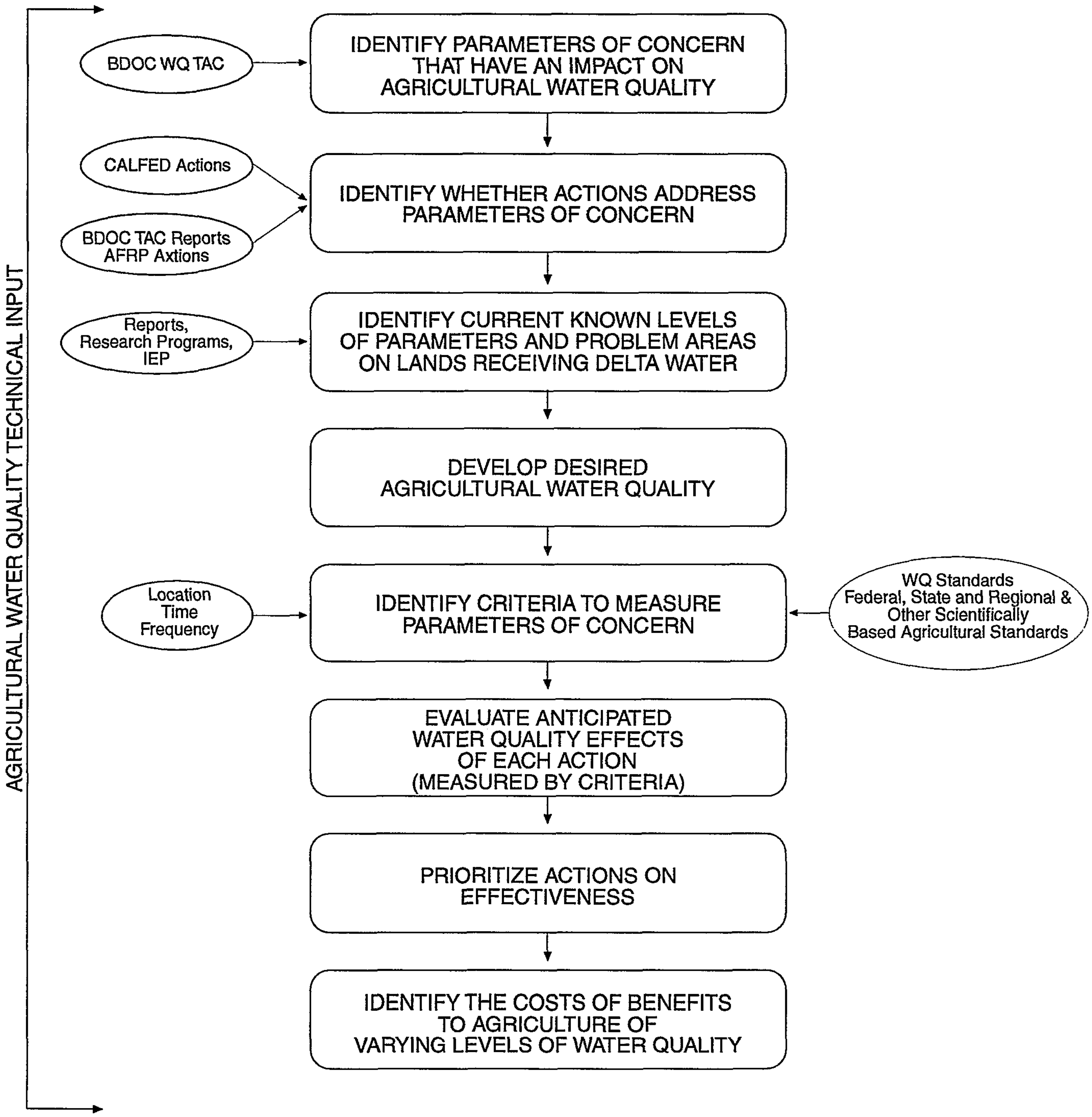

FIGURE 3
PROPOSED AGRICULTURAL SUBTEAM PROCESS TO ADDRESS THE AGRICULTURAL COST OR BENEFIT OF DIFFERENT WATER QUALITIES IN THE DELTA
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supply. Issues associated with agricultural return flows were primarily addressed relative to the following:

- Return flow impacts on irrigation water quality downstream
- The influence of a field's drainage on water supply requirements
- The impact of water supply quality on drainage volume and quality

Water quality criteria developed by the subteam are not intended for regulatory application. Rather, they are analytical tools for the CALFED process. CALFED goals and solution principles suggest that actions may improve irrigation water quality in parts of the Delta, and should not result in significant degradation of water quality in export areas. To help guide such an effort, the CALFED process must have a working definition of what good agricultural water quality is. Clearly, such criteria are not, and will not be achievable at all times and places in the water distribution system. For example, data presented in this report illustrate that water not meeting the specified criteria is currently delivered to many farms. While actions associated with CALFED may result in some improvement, they cannot address each of these agricultural water quality challenges in their entirety.

The subteam also reviewed proposed CALFED actions from a water quality perspective. Few of the actions relate directly to improving or maintaining the quality of the agricultural water supply. Rather, a number primarily relate to agriculture through their focus on management of agricultural drainage and related problems. Thorough consideration of CALFED actions continued after the subteam's dissolution, by the CALFED Water Quality Technical Group, into which the subteam's membership was incorporated. The subteam's understanding of and commentary on the actions was incorporated in this later work. CALFED actions are therefore not discussed in this report of the subteam, but rather in the CALFED Water Quality Technical Group's report.

Agricultural Water Quality Linkages

Water quality requirements for agriculture are simple in the sense that water quality requirements for existing crops needs to be achieved at every headgate, and agricultural water quality requirements can be established from available research. However, complexity arises from consideration of the following variables, which affect water quality:

- Water quality within the full extent of the delivery system

- Variations in cropping patterns

- Variations in water supply levels

- Recycling of tailwater and subsurface drainage water

- Environmental and regulatory standards for drainage water quality
- Regulatory and contractual standards for water supply quality
- Influence of water quality on sustainability as well as the current economic product of agriculture
- Future changes in water management (50-year planning horizon)

The following sections discuss several of these linkages in more detail.

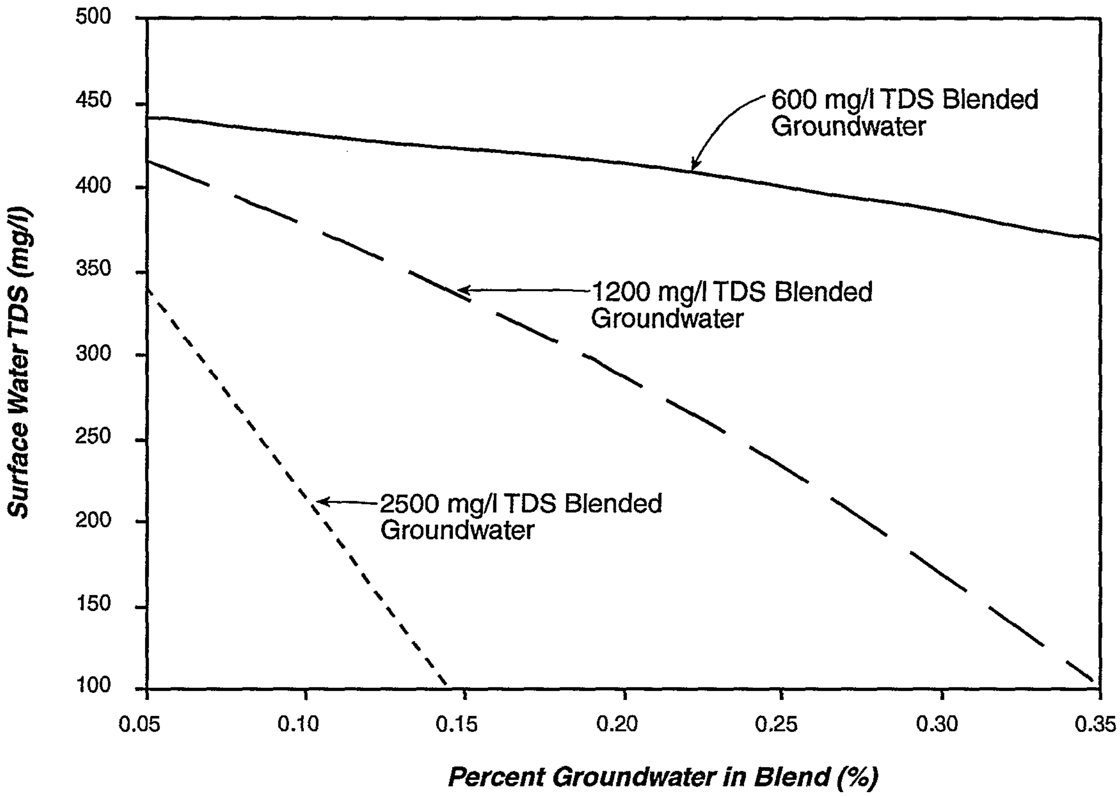
Linkage To Water Supply

Water quality requirements depend on the crop being grown. However, it can equally be said that farmers will grow crops requiring higher quality water (since they are often of higher value) when such water is available. Therefore, farmers want the best possible water quality. In a year with full water deliveries, this is much less problematic than in dry years when deliveries are curtailed.

During dry years, surface water supply shortfall is supplemented by groundwater that is often of lower quality (higher salinity). Surface water is blended with groundwater to achieve acceptable salinity levels. The relationship between surface water quality, groundwater quality, and required blend ratios are illustrated in Figure 4. For a given groundwater quality, higher quality surface water results in a greater percentage of groundwater in the blend. Likewise, higher quality groundwater allows for a greater percentage of groundwater in the blend. Of course, when surface water is plentiful, little blending occurs, and more water is irrigated as is.

Furthermore, as more saline water is used for irrigation, a larger fraction of leaching water is required (Figure 5), and applied water and subsurface drainage volumes increase (Figure 6). If adequate leaching and subsurface drainage are provided with more saline irrigation water, then salt loads from irrigated lands increase, although the salinity of drainage may not (Figure 7). Alternatively, if adequate leaching is not provided, soil salinity increases (Figure 8) and drainage water quality declines (Figure 9). As irrigation water quality declines, tailwater and drainage recycling are curtailed. Therefore, the quantity and quality of irrigation supply and subsurface drainage waters are inextricably linked for agriculture.

Another example of this fact is in the Sacramento Valley, where increasing measures for water conservation, such as reduced through-flow irrigation and



NOTES:

Blend ratios calculated with assumed groundwater TDS values for the Westside ground water basin, which consists mainly of lands in the Westlands Water District on the west side of the San Joaquin Valley.

DWR estimates the groundwater quality of the Westside basin to be in the range of 600-2,500 mg/l TDS, based on active monitoring data.

REFERENCES:

California Department of Water Resources, 1980, "Ground Water Basins In California," Bulletin 118-80.

Westlands Water Distict, 1995, "December 1994 Groundwater Conditions," Water Conservation Program Report.

FIGURE 4
SURFACE WATER QUALITY REQUIRED RELATIVE TO BLEND RATIOS TO PRODUCE 450-MG/L (TDS) BLENDED WATER
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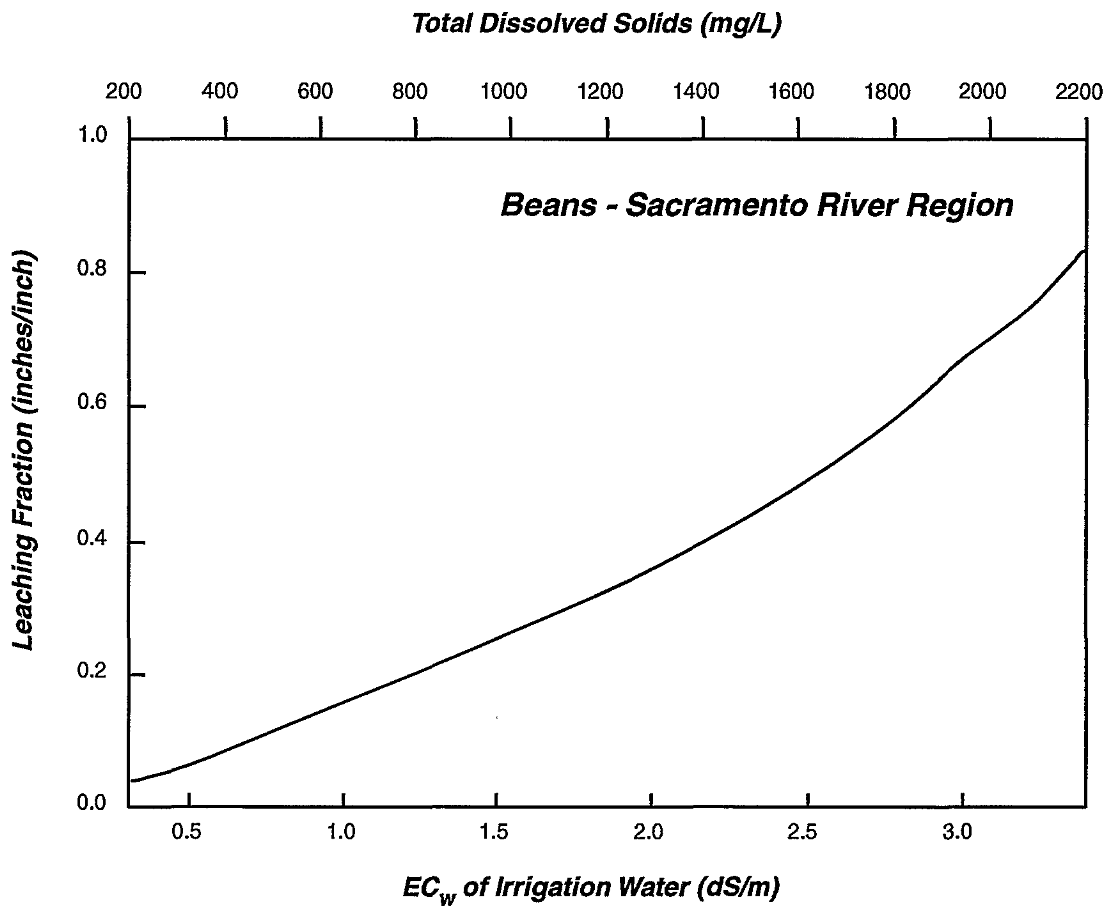

ASSUME:
ECe for 90% Yield Potential of Beans = 1.5 dS/m, FAO 29, 1985.
$LR = EC_w / (5*EC_e - EC_w)$, Eq. 9, FAO 29, 1985.

NOTE:
Leaching requirement may be satisfied by irrigation inefficiencies during water application.

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FIGURE 5
LEACHING REQUIREMENT RELATIVE TO IRRIGATION WATER QUALITY
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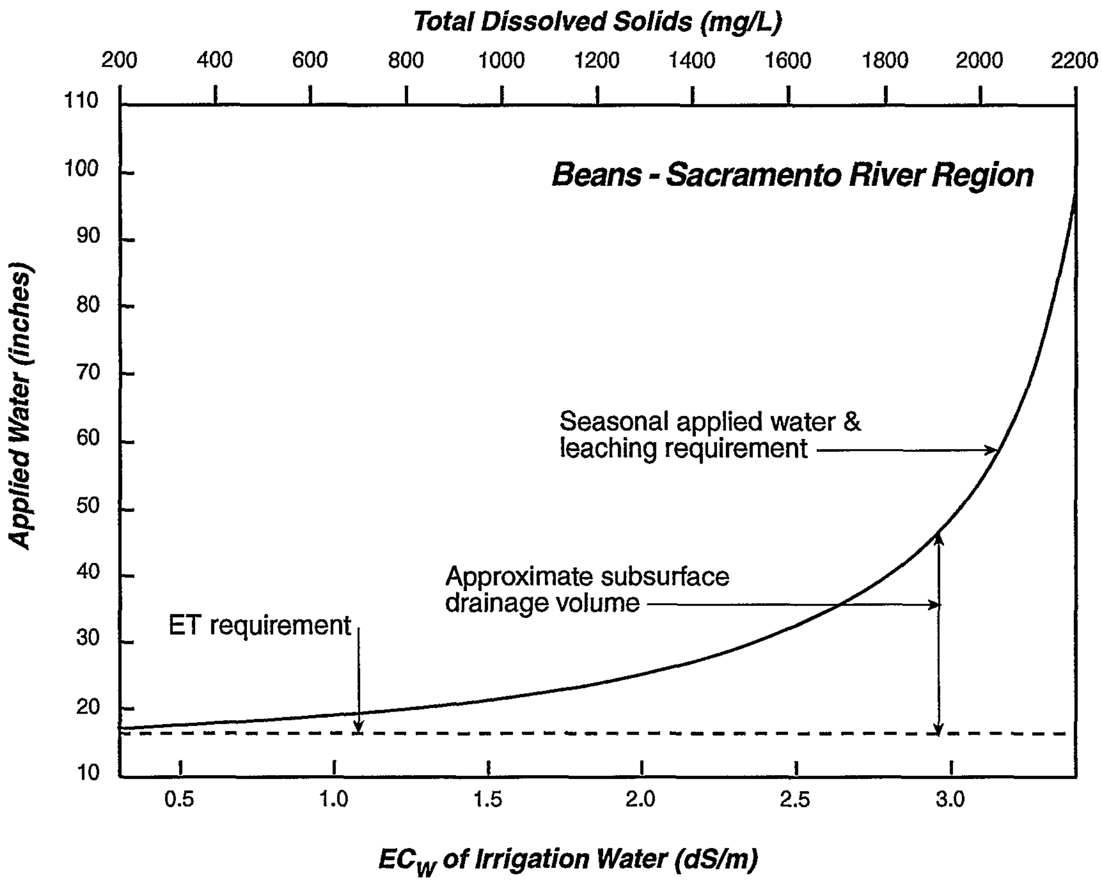

ASSUME:
ECe for 90% Yield Potential of Beans = 1.5 dS/m, FAO 29, 1985.
Evapotranspiration (ET) requirements for Beans in the Sacramento River Valley is based on a seasonal ET estimate of 16.2 inches from Table 22, DWR Bulletin No. 113-3, 1975.
$LR = EC_w/(5*EC_e - EC_w)$, Eq. 9, FAO 29, 1985.
Irrigation system has an application efficiency of 80% and high distribution uniformity.

NOTE:
Leaching requirement may be satisfied by irrigation inefficiencies during water application as depicted in some cases.

FIGURE 6
IRRIGATION AND SUBSURFACE DRAINAGE VOLUME RELATIVE TO IRRIGATION WATER QUALITY
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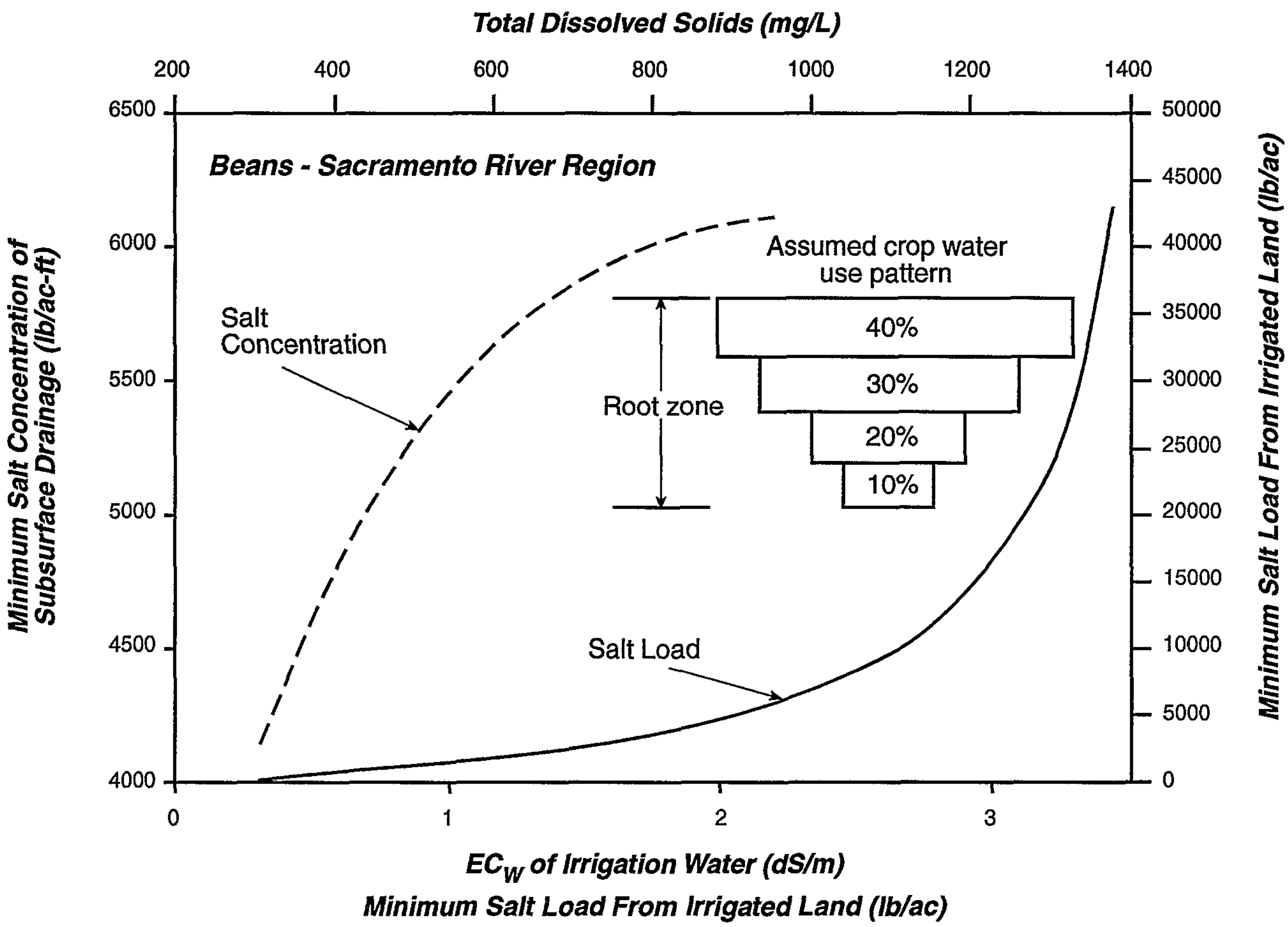

ASSUMPTIONS:
ECe for 90% Yield Potential of Beans = 1.5 dS/m, FAO Irrigation and Drainage Paper 29, 1985.
Evapotranspiration (ET) requirements for Beans in the Sacramento Valley is based on a seasonal ET estimate of 16.2 inches from Table 22, DWR Bulletin No. 113-3, 1975.

$LR = EC_w/(5*EC_e - EC_w)$, Eq. 9, FAO 29, 1985.

The irrigation system has a high distribution uniformity. Assume crop water use extraction pattern of 40-30-20-10 as depicted. This assumes that the prescribed leaching fraction, shown in Figure 6, is applied.

FIGURE 7
SUBSURFACE DRAINAGE SALINITY RELATIVE TO IRRIGATION WATER
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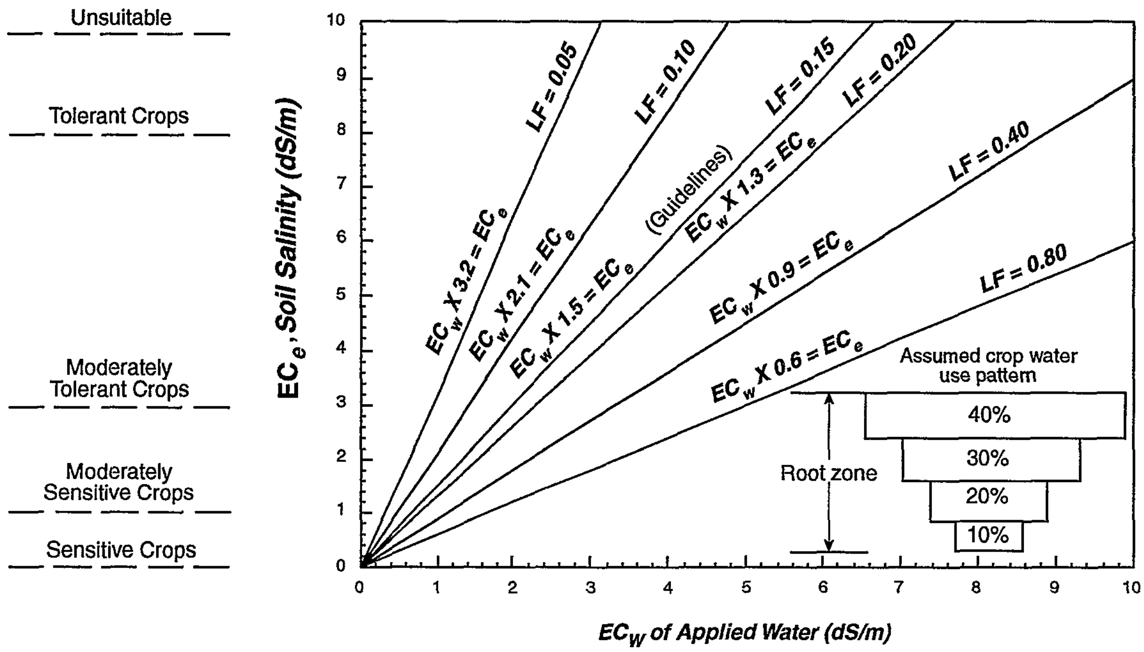

SOURCE:
Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29.

NOTE:
Leaching Fraction (LF) is based on general crop rotations. For particular crop estimates, use the methods presented in the source document.

FIGURE 8
EFFECT OF APPLIED WATER SALINITY (EC_W) ON SOIL SALINITY (EC_e) AT VARIOUS LEACHING FRACTIONS
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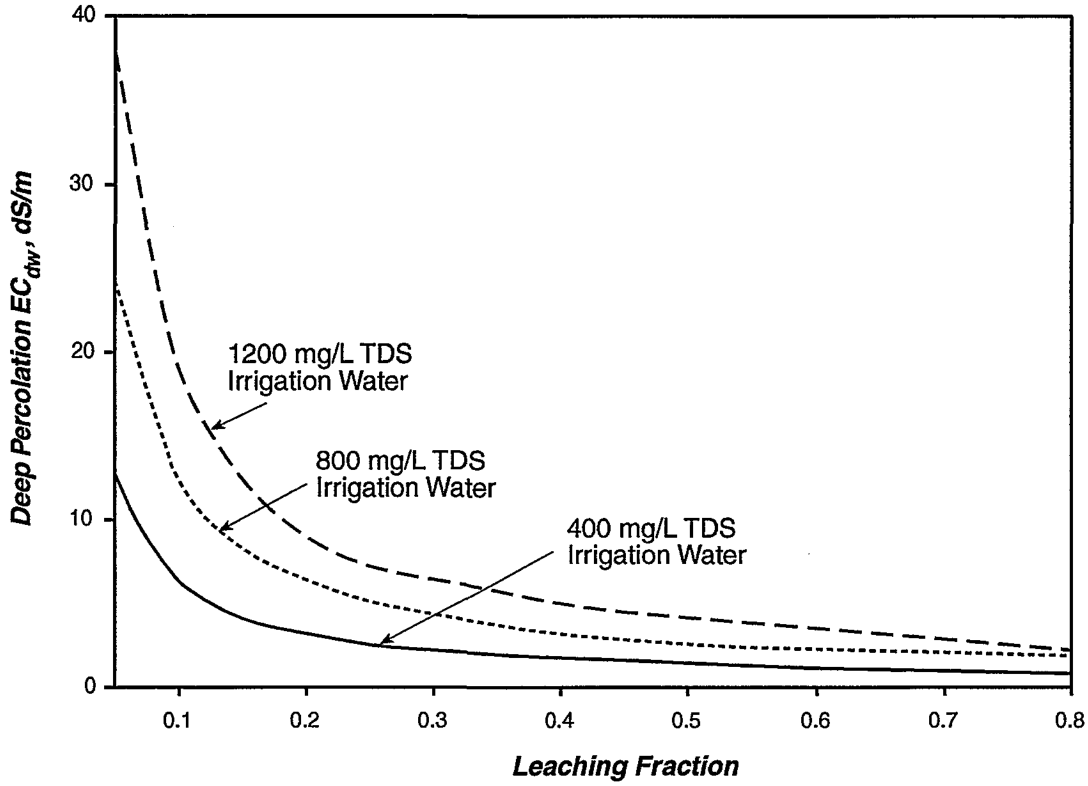

NOTES:
The concentration of the soil water percolating below the root zone (ECsw) is equivalent to the concentration of the drainage water (ECdw) accumulating below the root zone.

$EC_{dw} = EC_{sw} = EC_w/LF$

REFERENCES:
Ayers R.S. and D.S. Westcott. 1985. Water Quality for Agriculture. FAO 29.

FIGURE 9
ESTIMATED CONCENTRATION OF DEEP PERCOLATION FROM THE BOTTOM OF THE ROOT ZONE
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increased tailwater recycling in rice fields, have led to increases in soil and water salinity, especially at the "low end" of agricultural water delivery systems. Therefore, the water quality requirement at the last, downstream headgate may be the key to establishing water quality criteria at the initial diversion. These and other facts of agricultural water use should be taken into account as actions are prioritized for inclusion in the CALFED programs.

Linkage to Ongoing Programs and Existing Standards

Existing agricultural water quality programs need to be considered by CALFED so that ongoing efforts are fairly recognized and duely supported. Some examples of existing water quality programs include the following:

- San Joaquin Valley Drainage Improvement Program (multi-agency, DWR)
- Drainage Reduction Program (DWR)
- Rice Herbicide Program (Central Valley Regional Water Quality Control Board [CVRWQCB])
- Inland State Water Resources Control Board Surface Waters Act Task Force recommendations
- Watershed planning and drainage control programs at basin, watershed, local, and district levels

Regulatory and contractual criteria already exist for many locations, and CALFED should not specify criteria that are less stringent. For example, there are contractual (U.S. Bureau of Reclamation [USBR]) criteria for Mendota Pool. Many factors influence this water quality, including upstream drainage inflows to DMC (some undocumented), and the extent of groundwater integration along the DMC. Other examples of existing criteria include the following:

- CVRWQCB Basin Plan
- Water quality standards (e.g., Vernalis)
- Water quality performance goals (e.g., Colusa Basin Drain)

Linkage to Irrigation and Drainage Management

Guidelines presented in this document for acceptable ranges of various parameters (including salinity) depend on a number of irrigation and drainage management assumptions. The pertinent assumptions are catalogued in Ayers and Westcot (1985). Some examples include:

- A 15 percent leaching fraction is included in applied water. If this is not the case, then more water or water of better quality is required.

- Surface or sprinkler irrigation with adequate drainage are assumed. Guidelines must therefore be modified for subsurface irrigation (common within the legal Delta), for drip irrigation (increasingly common in the San Joaquin Valley), and for situations in which subsurface drainage is inadequate (such as drainage-affected areas in the San Joaquin and Sacramento valleys and Delta).

- A particular, vertical distribution of water uptake from the root zone is assumed: 40 percent of water uptake from the top 25 percent of the root zone; 30 percent from the next 25 percent; 20 percent from the next 25 percent; and 10 percent from the bottom 25 percent.

- Good irrigation and drainage uniformity is assumed. Within-field variability of irrigation application and drainage was not considered as part of the development of these criteria. Figure 10 illustrates the relationship between irrigation distribution uniformity (DU), water requirements, and irrigation scheduling. The DU describes how evenly water is made available to plants throughout a field. When irrigation events are scheduled and applied properly to meet crop and leaching needs, better DU can result in lower subsurface drainage volumes while more fully meeting crop and leaching needs throughout the field.

To the extent that these and other assumptions are not met, the criteria should be modified to provide adequate water quality based on local constraints.

Linkage to Conveyance System Extent and Operation

The geographic scope of agricultural water use related to the Delta includes all agriculture in tributary regions, and all agriculture in areas whose water supply passes through the Delta. This would include, for example, the Sacramento Valley and Southern California areas receiving State Water Project water for irrigation.

Ayers and Westcot (1985) water quality criteria are given according to the level of crop (yield) sensitivity to declining water quality. For a given parameter, more sensitive crops require higher quality water to sustain full (or desired) yields. Since conveyance systems mix water delivered to the full

IRRIGATED FIELD AREA

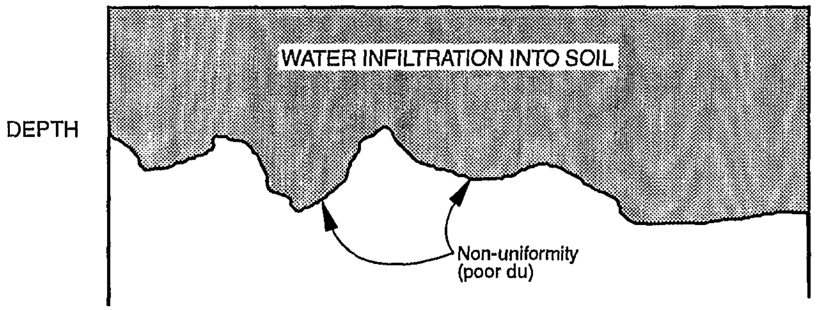

FIGURE A: The concept of non-uniformity

NOTE: Regardless of the irrigation method, there are differences in the amount infiltrated at different points on the field, some sprinklers and emitters may be partially plugged and pressure and flow may vary within the irrigation system. Water sits at the head end of a furrow longer than at the tail end. *These are just a few of the many* causes of non-uniformity.

IRRIGATED FIELD AREA

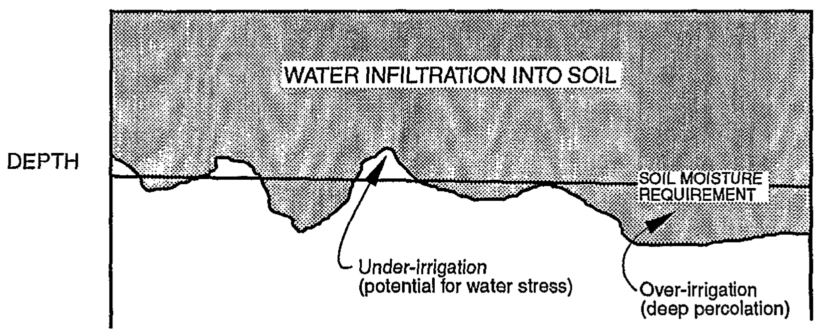

FIGURE B: The concept of adequacy of irrigation.

NOTE: In the case shown above, some of the field receives enough water and some is under-irrigated. The deep percolation is "lost" to that field, along with nutrients that leach with the water.

IRRIGATED FIELD AREA

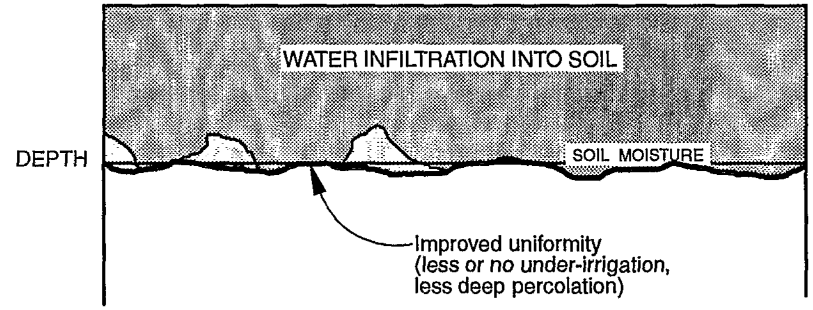

FIGURE C: The concept of improved uniformity

NOTE: The same amount of water is applied as in Figure B, but with a better DU. The result is less (or no) under-irrigation, and less deep percolation.

IRRIGATED FIELD AREA

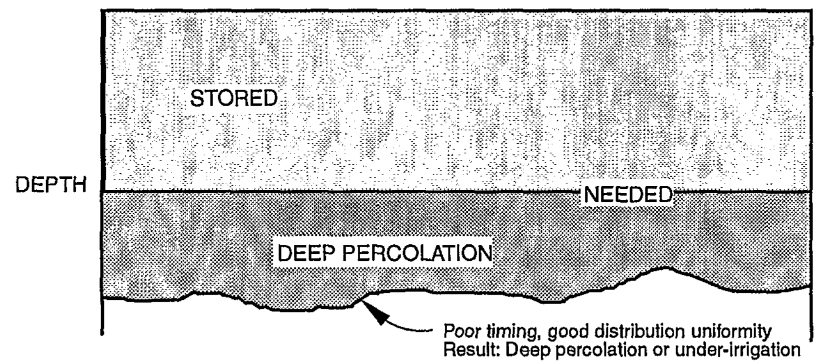

FIGURE D: The concept of irrigation efficiency and distribution uniformity

NOTE: A good DU, but too much water was applied, resulting in large amounts of deep percolation.

SOURCE: ITRC. California State University at San Luis Obispo, 1993, Agricultural Irrigation Management Manual.

FIGURE 10
TWO-DIMENSIONAL SKETCHES REPRESENTING THE CONCEPTS OF IRRIGATION UNIFORMITY AND APPLICATION EFFICIENCY

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range of crops grown in the region, agricultural water quality standards should be based on the most sensitive crops grown in the region. For example, strawberry, carrot, and beans require an electrical conductivity (EC_w) < 0.7, or Total Dissolved Solids (TDS) < 450 mg/L.

Parameters of Concern

Both the quantity and quality of water supply are important for irrigation. A water supply must be adequate to fulfill anticipated irrigation needs. However, poor quality water is applied special management practices may be required to maintain full crop productivity. The problems that result from using poor quality water will vary in type and severity. Some impacts are osmotic effects on plant growth and crop yield, effects on soil permeability and infiltration, and specific ion toxicities. Other problems that can arise include excessive vegetative growth, lodging, or delayed crop maturity resulting from excessive nutrients (usually nitrogen) in the water supply; white deposits on fruit or leaves caused by sprinkling with waters high pH; and others discussed in this report. The primary factors in evaluating water quality for irrigation however, are the quantity and kind of salt present in the water supply.Water quality parameters of concern for agriculture and their effects are summarized in Table 1. Each of the parameters will be described in more detail in individual sections following this general discussion, including the rationale for inclusion and potential level of impact on crop yield, criteria for irrigation water, and agricultural management techniques used when criteria are not met.

Guidelines for evaluating water quality based on the parameters of concern for irrigation are summarized in Table 2. Information contained in Table 2 relative to the degree of restriction in use is drawn mainly from Table 1 in Ayers and Westcot (1985). A number of critical assumptions are associated with these guidelines, and a summary of some of these assumptions provided in this section has been extracted from the same document.
These guidelines are limited to irrigation water quality characteristics that commonly affect crop production. Emphasis is on long-term, dominating influences of water quality on soil-plant-water systems as it relates to crop production. The guidelines in Table 2 are intended as a management tool only, and the user should guard against drawing unwarranted conclusions based strictly on generalizations.

The water quality guidelines in Table 2 are intended to cover the wide range of conditions encountered in irrigated agriculture. They incorporate some of the newer concepts in soil-water-plant relationships. Several basic assumptions have been used to define their range of usability. If the water is used under very different conditions, the guidelines may be adjusted. Wide deviations

Table 1
Parameters of Concern and Their Effects on Agricultural Water Quality

Parameters	Frequency of Effect[a]	Source	Affected Factors	Geographic Area of Concern
Salinity (TDS & EC)	high	seawater, agricultural drainage	crop yield, soil management	All irrigated areas in western & central Delta, parts of the San Joaquin and Sacramento river valleys
SAR (Sodium)	medium	seawater, agricultural drainage	crop yields, sensitive crops (tree crops, beans, etc.), soil structure, and management	All irrigated areas in western & interior Delta
Chloride	medium	seawater, soil structure, and agricultural drainage	crop yield, plant necrosis	Fresh market produce production
Boron	medium	groundwater	crop yield, drying and chlorosis, irrigation	High-B groundwater source areas - Yolo County
pH	medium	groundwater	greenhouses, $CaCO_3$ precipitation	Southern San Joaquin Valley, Southern California
Turbidity	low	Delta & tributary watersheds during flood events	sedimentaion of open channels, clogging of sprinkle and drip irrigation systems, soil crusting	All areas
Nutrients (Nitrate)	low	wastewater discharge	algae in drains, clogging, NO_3 - beets, grapes, etc.	Areas diverting from tailwater and municipal wastewater receiving waters
Temperature	low	snowmelt	rice crop yield (cold water effects on germination)	Irrigated rice acreage in the Sacramento Valley

[a]Relative indication of frequency of crop production problems related to parameter within the geographic scope of this report.
Source: Initial report of the Water Quality Technical Advisory Committee, Bay-Delta Oversight Council, Draft, December 1994.

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Table 2
Guidelines for Water Quality Ranges of Parameters for Irrigation

Parameters	Units	Water Quality for Irrigation[a] Degree of Restriction on Use			Drinking Water Standards[h] U.S. EPA			Basin Plan Water Quality Objectives - RWQCB[m]				
		None	Slight to Moderate	Severe	Primary MCL	Secondary MCL	MCL Goal	Central Valley	Tulare[l]	Ventura - Lan[n]	Santa Ana River[o]	Sac-San Joaquin
Salinity Ec_w[b]	dS/m or mmho/cm	<0.7	0.7 - 3.0	>3.0				1.0[i]	1.0			1.0[r]
TDS	mg/l	<450	450-2000	>2000		500		125[j]	700	450-2000	700	
SAR[c]												
= 0 - 3	EC_w	>0.7	0.7 -0.2	<0.2								
= 3 - 6	EC_w	>1.2	1.2 - 0.3	<0.3								
= 6 - 12	EC_w	>1.9	1.9 - 0.5	<0.5								
= 12 - 20	EC_w	>2.9	2.9 - 1.3	<1.3								
= 20 - 40	EC_w	>5.0	5.0 - 2.9	<2.9								
Chloride[d,e]	µg/L					250,000		106,000[h]	175,000	100,000-355,000	175,000	
Surface irrigation	mg/L	<4	4-10	>10								
Sprinkle irrigation	me/L	<3	>3									
Boron	mg/L	<0.7	0.7 - 3.0	>3.0				0.7[h]	1.0	0.5 - 4.0	0.75	
Alkalinity ($CaCO_3$)[f]	me/L	<1.5	1.5 - 8.5	>8.5								
Turbidity	NTU				0.5 or 1.0						20%[p]	
Temperature	Deg F							55-70[k]			Varies[q]	
Nutrients												
Nitrate[g]	mg/L	<5	5 - 30	>30						10	10	

[a] Adapted from University of California Committee of Consultants (1974) and Ayers and Westcot (1985). The basic assumptions of the guidelines are discussed following these notes.

[b] EC_w means electrical conductivity of the irrigation water, reported in mmhos/cm or dS/m. TDS means total dissolved solids, reported in mg/l.

[c] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. See Ayers and Westcot* Figure 1 for the SAR calculation procedure. At a given SAR, infiltration rate increases as salinity EC_w increases. Evaluate the potential permeability problem by SAR and ECw in combination. Adapted from Rhoades* and Oster and Schroer*.

[d] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance in Ayers and Westcot* or equiv.

[e] For overhead sprinkle irrigation and low humidity (<30 percent), sodium and chloride greater than 70 or 100 mg/l, respectively, have resulted in excessive leaf adsorption and crop damage to sensitive crops, see Ayers and Westcot*.

[f] Overhead sprinkling only.

[g] NO_3 - N means nitrate nitrogen reported in terms of elemental nitrogen.

[h] J. B. Marshak, 1995. California Reqional Water Quality Control Board, Central Valley Region. A Compilation of Water Quality Goals.

[i] Export value from multiple scenarios presented in Central Valley Basin Plan. Value varies with time of year, location, and water year type.

[j] Central Valley Basin Plan, Table III-3, assumes 90 percentile value.

[k] Central Valley Basin Plan, Table III-4.

[l] Tulare Basin Plan for mineral quality of irrigation water that may recharge to good quality ground waters.

[m] Water Quality Control Plan for the San Diego Basin, Table 3-1 cites criteria identified to "Water Quality for Irrigation" in this table.

[n] Water Quality Objectives Table 3-8 Beneficial Use Categories in Ventura Basin Plan.

[o] Water Quality Control Plan for Inland Surface Waters in Santa Ana River Basin.

[p] For the 0 - 50 NTU range a 20% increase is allowed.

[q] Cold waters increases < 5 deg F, Warm waters shall remain < 90 deg F June thru Oct and > 78 deg F the rest of the year. Lake temps shall not be raised more than 4 deg F.

[r] For export waters based on the 1991 Bay-Delta Plan.

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from the assumptions might result in wrong judgments on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research, or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

1. Yield Potential-Full crop production, including necessary management inputs, is assumed when the guidelines indicate that water quality does not constitute a problem. The existence of a potential problem indicates that certain tolerant crops may have to be grown to maintain full productivity. It does not indicate that the water is unsuitable for use on any crop.

2. Site Conditions (Soil and Climate)-Soil textures ranging from sandy-loam to clay-loam are assumed with good internal drainage. The climate is semi-arid to arid with low effective rainfall. Drainage is assumed to be good, with no uncontrolled shallow water table present.

3. Methods and Timing of Irrigation-Normal surface or sprinkler irrigation methods are assumed including flood, basin, strip-check, furrow, corrugation, and sprinkle. It is assumed the crop uses a considerable portion of the stored plant-available soil water between irrigations (50 percent or more). With these irrigation methods, about 15 percent of the applied water is assumed to percolate below the rooting depth, this translates into an approximate leaching fraction of 15 percent. The guidelines are too restrictive for specialized irrigation methods, such as localizeddrip irrigation, which results in near daily irrigation events, but are applicable for subsurface irrigation if surface-applied leaching satisfies the leaching requirement.

4. Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average, about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent form the lowest quarter. Each irrigation is assumed to leach the upper root zone and maintain it at a relatively low salinity. Salinity is assumed to increase with depth to the lower part of the root zone. The average salinity of the soil-water is assumed to be three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15 to 20 percent and irrigation events that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part, but a salt balance is achieved (assuming the soil is at equilibrium and water quality remains constant) as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, more active part of the root zone and long-term leaching is accomplished.

Restrictions on Use

The Restriction on Use is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clearcut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials, and observations have led to these divisions, but management skills of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

The following sections discuss individual parameters of concern.

Salinity

All irrigation water is a mixture of pure water and some salts (salts are molecules which separate into positive and negative ions when dissolved in water). The irrigation water quality (chemistry) affects the amount and type of salts found in soil. When water is applied as irrigation, crop uptake and evaporation remove pure water with some dissolved salts, particularly nutrient salts. However, most of the water's salt load remains in the crops root zone after uptake of water by roots. When water does not leach from the soil, but is only added to meet crop needs, the soil accumulates residual salt over time. If the frequency of leaching is too low, then salt concentrations may reach levels that stress growing plants.

In general, salt influences plant growth by depriving the roots of water. Water uptake by plants is driven by differences in water content and salt concentration between the root interior and the soil. When the salt concentration of the soil increases, plants must accumulate salt themselves, or must dehydrate to continue to extract water from the soil.

Plants vary in their ability to adapt to saline conditions by these and other mechanisms; and therefore, vary in their ability to tolerate saline conditions. Even tolerant plants, though they survive, may not produce as much when grown under saline conditions. This is because extraction of water from saline soil requires more plant energy, which might otherwise be allocated for plant growth and metabolism.

In addition to crop water uptake, salinity can affect agronomic systems in other ways; if there is a disproportionate amount of sodium in the water, the soil surface can seal, causing infiltration problems. Some specific types of salt are highly toxic to plants in relatively low concentrations. High salt levels can also inhibit water uptake by seeds, germination, and crop emergence.

Criteria

The water quality requirements of crops grown in areas served by the Delta dictate agricultural salinity criteria. A map of DWR hydrologic regions is shown on Figure 11. The regions considered tributary to, or served from the Delta are the Sacramento River, San Joaquin River, Tulare Lake, and South Coast hydrologic regions. Acreage of crops grown within these regions are shown in Table 3. Crops are grouped within each region as major, intermediate, or minor in importance based on their percentage of total acreage. For each crop group in each of the four regions shown in Table 3, the effect of increasing irrigation water salinity has been illustrated. Figures 12, 13, 14, and 15 show these relationships. If the most sensitive crops are considered, irrigation water salinity levels at or below the criterion of 450 mg/L TDS are required to avoid yield reductions due to salinity.

Management

The major objective in selecting management practices to control salinity is to maintain adequate soil water availability to the crop. Procedures that require relatively minor changes in management are more frequent irrigation events, selection of more salt-tolerant crops, additional leaching, pre-plant irrigation events, and altered seed placement. Alternatives that may require significant changes in management are changing the irrigation method, altering the water supply, land-grading, modifying the soil profile (deep ripping), and installing artificial drainage. Management practices must fit the method of irrigation. A summary of the factors affecting the selection of an irrigation method under saline conditions is presented in Table 4. Although some of these management options are relatively easy to implement, the economic impact may make them impractical depending on the agronomic system in place.

Corn has been shown to tolerate some salinization under sub-irrigated conditions, but eventually requires leaching. After salinization, one study showed 10 to 15 percent salt removal by leaching that should theoretically remove 50 percent of accumulated salinity (Mass & Hoffman, 1983). Field realities may influence saline land management.

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SOURCE:
CALIFORNIA WATER PLAN UPDATE,
BULLETIN 160-93
DWR, OCTOBER 1994

FIGURE 11
DWR HYDROLOLGIC REGIONS IN CALIFORNIA
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

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Table 3 Percentage of Acreage Harvested 1993			
Sacramento River Region, 1993			
Crop	Acres	Percentage (%)	Rank
Rice	450	22	Major
Other Field Crops Wild Rice, Milo	434	22	Major
All Hay & Pasture mostly Alfalfa	392	20	Major
Grains (Wheat)	278	14	Major
Tomatoes	130	6	Intermediate
Other Fruits & Nuts (Apricots)	112	6	Intermediate
Almonds	89	4	Intermediate
Walnuts	76	4	Intermediate
Citrus	14	1	Minor
Other Vegetables Onions	12	1	Minor
Grapes	11	1	Minor
Melons	10	0.5	Minor
Cotton	0	0	- - - -
Total	2,008	100	
Tulare Lake Region			
Crop	Acres (1,000)	Percentage (%)	Rank
Cotton	684	32	Major
Other Field Crops (Oats)	283	13	Major
All Hay & Pasture (mostly Alfalfa)	282	13	Major
Grains (Barley)	197	9	Intermediate
Citrus	162	8	Intermediate
Grapes	151	7	Intermediate
Almonds	116	5	Intermediate
Other Vegetables (mostly Watermelons)	108	5	Intermediate
Other Fruits & Nuts (mostly Figs)	82	4	Intermediate
Walnuts	32	2	Minor
Tomatoes	17	1	Minor
Melons	8	0.4	Minor
Rice	0	0	- - - -
Total	2,122	100	

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Table 3
Percentage of Acreage Harvested 1993

San Joaquin River Region

Crop	Acres (1,000)	Percentage (%)	Rank
All-Hay & Pasture (mostly Alfalfa)	673	22	Major
Cotton	502	16	Major
Other Field Crops (Corn)	427	14	Major
Grapes	370	12	Major
Almonds	272	9	Intermediate
Grains (Wheat)	183	6	Intermediate
Other Vegetables (mostly Carrots)	173	6	Intermediate
Tomatoes	165	5	Intermediate
Other Fruits & Nuts (mostly Apricots)	111	4	Intermediate
Melons	74	2	Minor
Walnuts	66	2	Minor
Citrus	46	1	Minor
Rice	19	1	Minor
Total	3,081	100	

South Coast Region[a]

Crop	Acres (1,000)	Percentage (%)	Rank
All-Hay & Pasture (Alfalfa and Irrigated Pasture)	587	75	Major
Citrus (All)	59	8	Major
Avocados	47	6	Major
Other Vegetables (mostly Onions, Broccoli, & Cauliflower)	34	4	Intermediate
Other Field Crops (mostly Corn, Beans)	15	2	Intermediate
Celery	11	1	Intermediate
Strawberries	8	1	
Lettuce	7	1	Intermediate
Grains	7	1	Minor
Tomatoes	6	1	Minor
Other Fruits & Nuts (mostly Peaches, Apples)	4	1	Minor
Cotton	0	0	- - - -

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Table 3
Percentage of Acreage Harvested 1993

Rice	0	0	----
Total	785	100	

Summary of All Regions

Crop	Acres (1,000)	Percentage (%)	Rank
All-Hay & Pasture	1,934	24	Major
Cotton	1,186	15	Major
Other Field Crops	1,159	14	Major
Grains	665	8	Intermediate
Grapes	532	7	Intermediate
Almonds	477	6	Intermediate
Rice	470	6	Intermediate
Tomatoes	319	4	Intermediate
Other Fruits & Nuts	310	4	Intermediate
Other Vegetables	328	4	Intermediate
Citrus	280	4	Intermediate
Walnuts	175	2.0	Minor
Melons	91	1	Minor
Avocados	47	0.6	Minor
Celery	11	0.1	Minor
Strawberries	8	0.1	Minor
Lettuce	7	0.1	Minor
Total	7,999	100	

[a] CAC, 1993 Report Data: Annual Bulletin. Compiled harvested acreages do not include portions of Riverside and San Bernadino Counties in the South Coast hydrologic area. Acreages for flowers, christmas trees, and various ornamentals, although substantial, were not available for inclusion.

Note: The South Coast hydrologic area is within the geographic scope of agricultural water use related to the Delta and currently receives SWP water, therefore, it is included in this harvested acreage summary.
Source:
CALFED Water Quality TAC from County Agricultural Commissioners (CAC) reports, various years.

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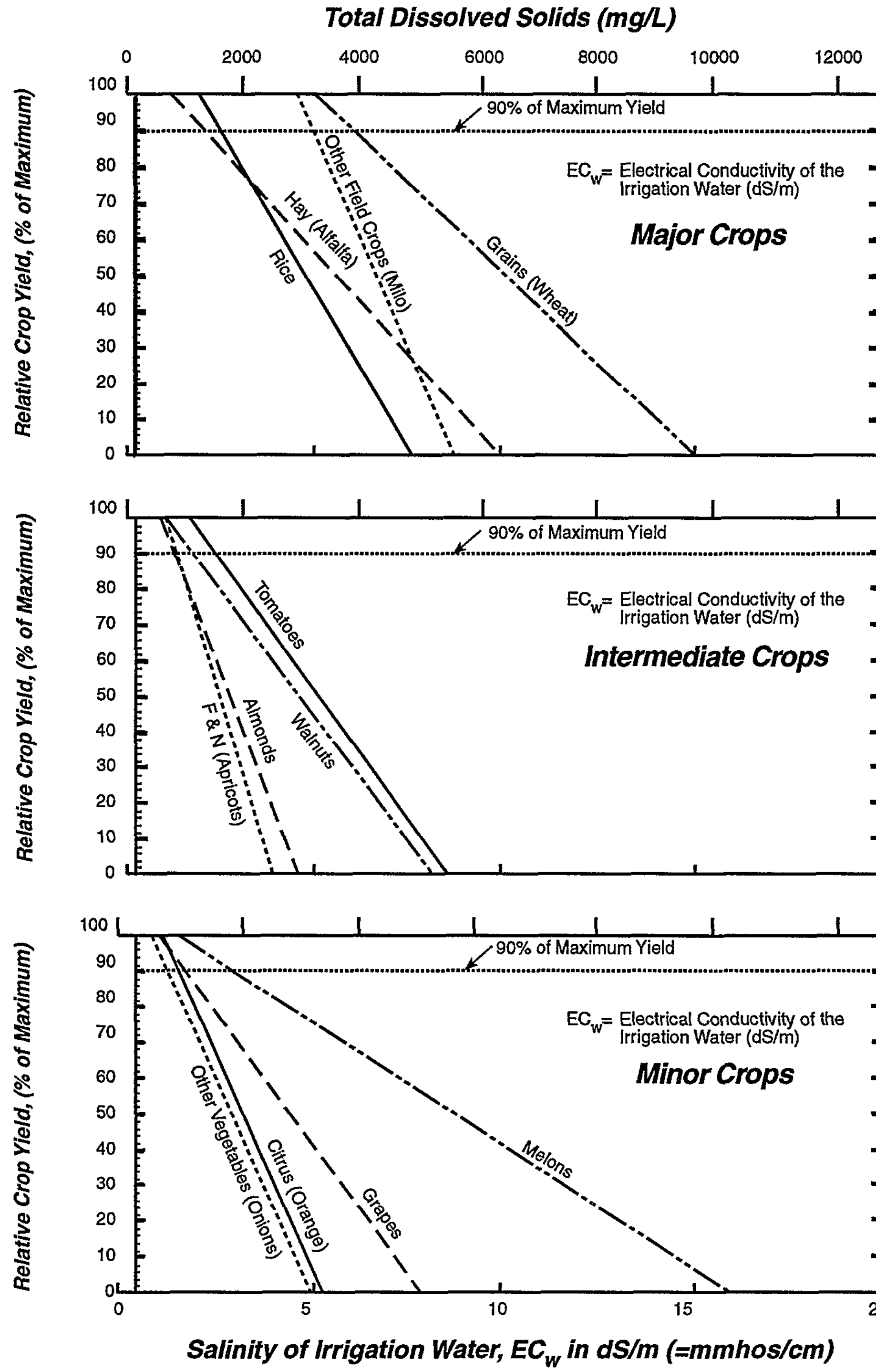

Source:

Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

FIGURE 12
SACRAMENTO RIVER REGION YIELD POTENTIAL AS INFLUENCED BY IRRIGATION WATER SALINITY
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

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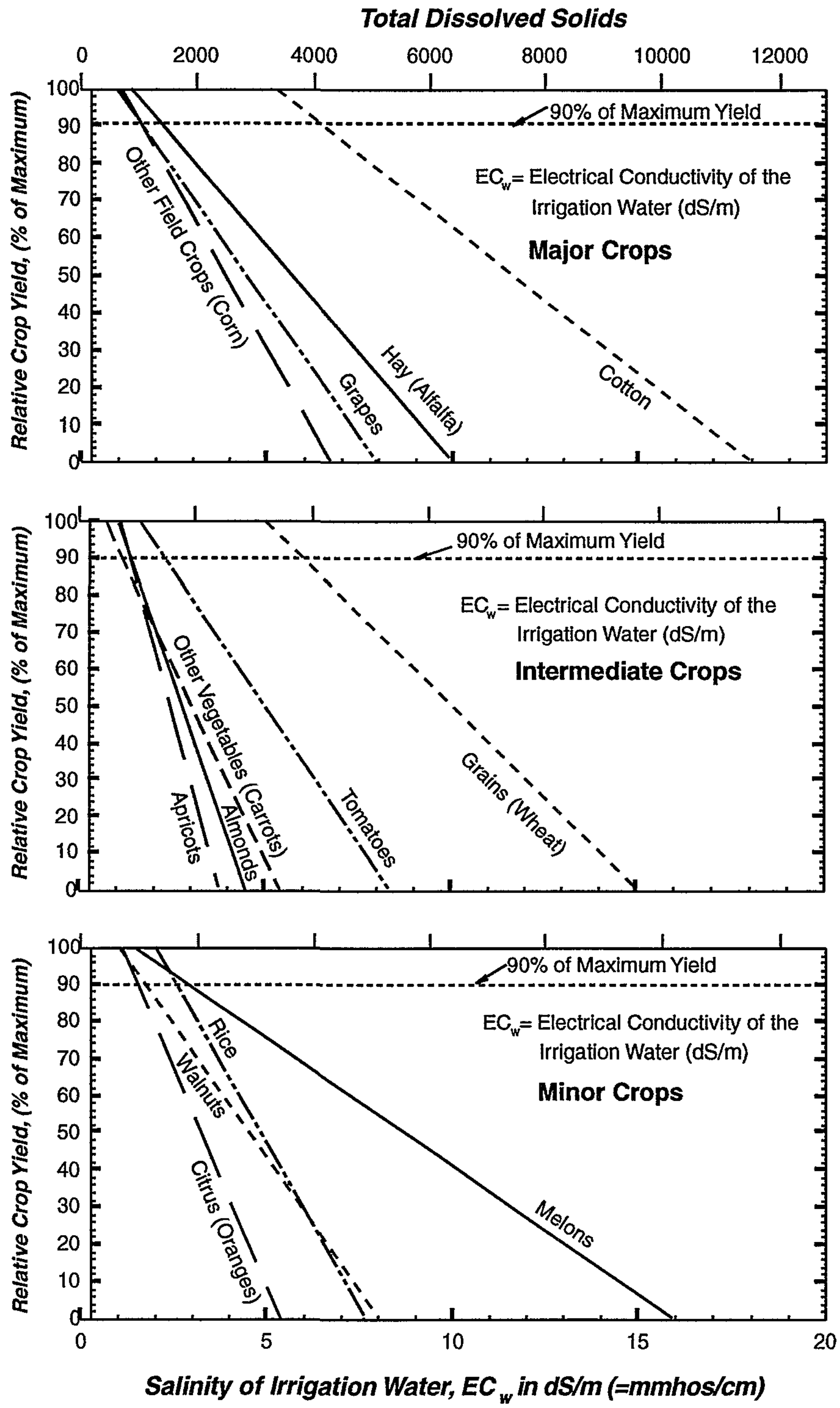

Source:

Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

FIGURE 13
SAN JOAQUIN RIVER REGION YIELD POTENTIAL AS INFLUENCED BY IRRIGATION WATER SALINITY
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

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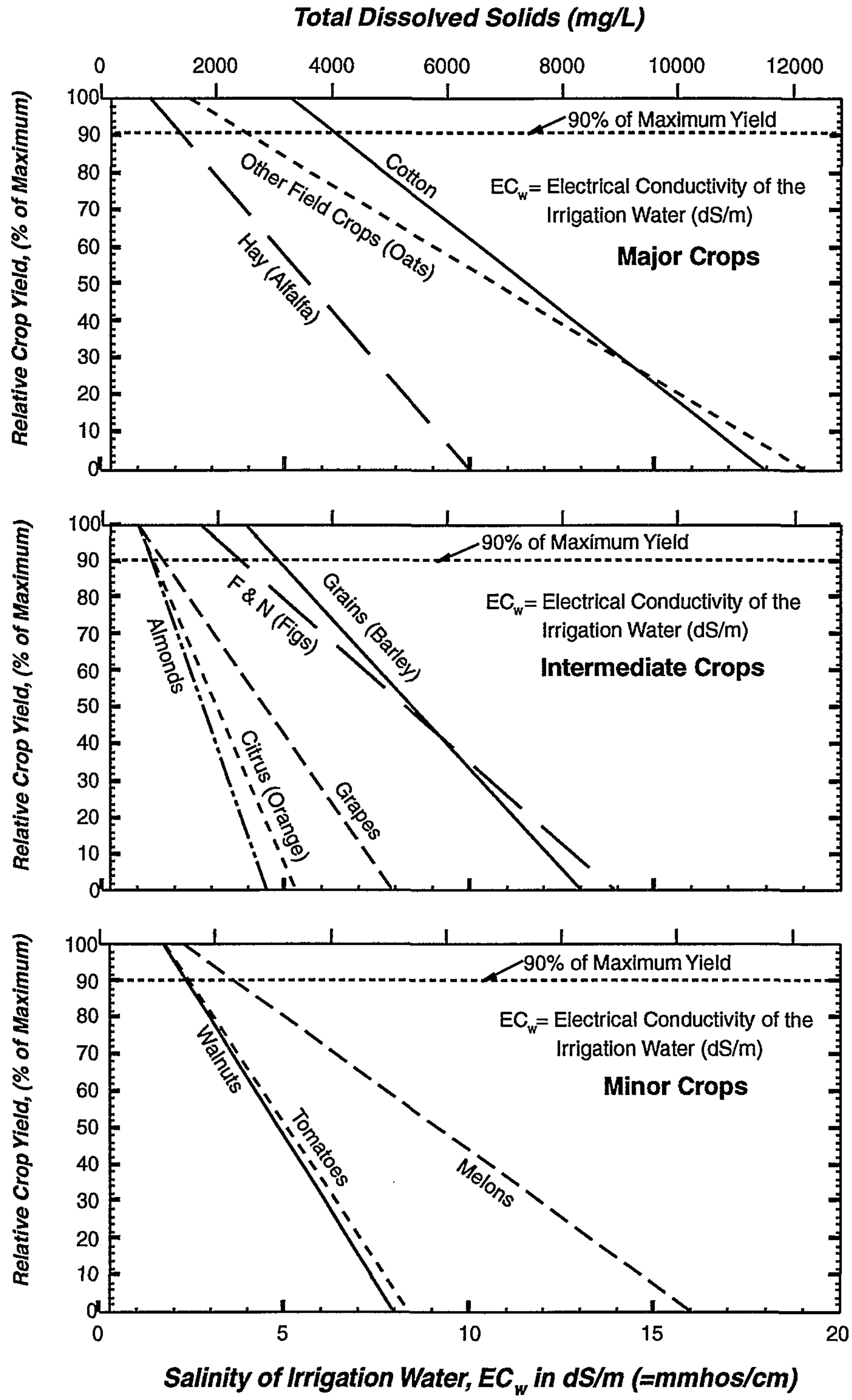

Source:
Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

FIGURE 14
TULARE LAKE REGION YIELD POTENTIAL AS INFLUENCED BY IRRIGATION WATER SALINITY
CALFED BAY-DELTA PROGRAM
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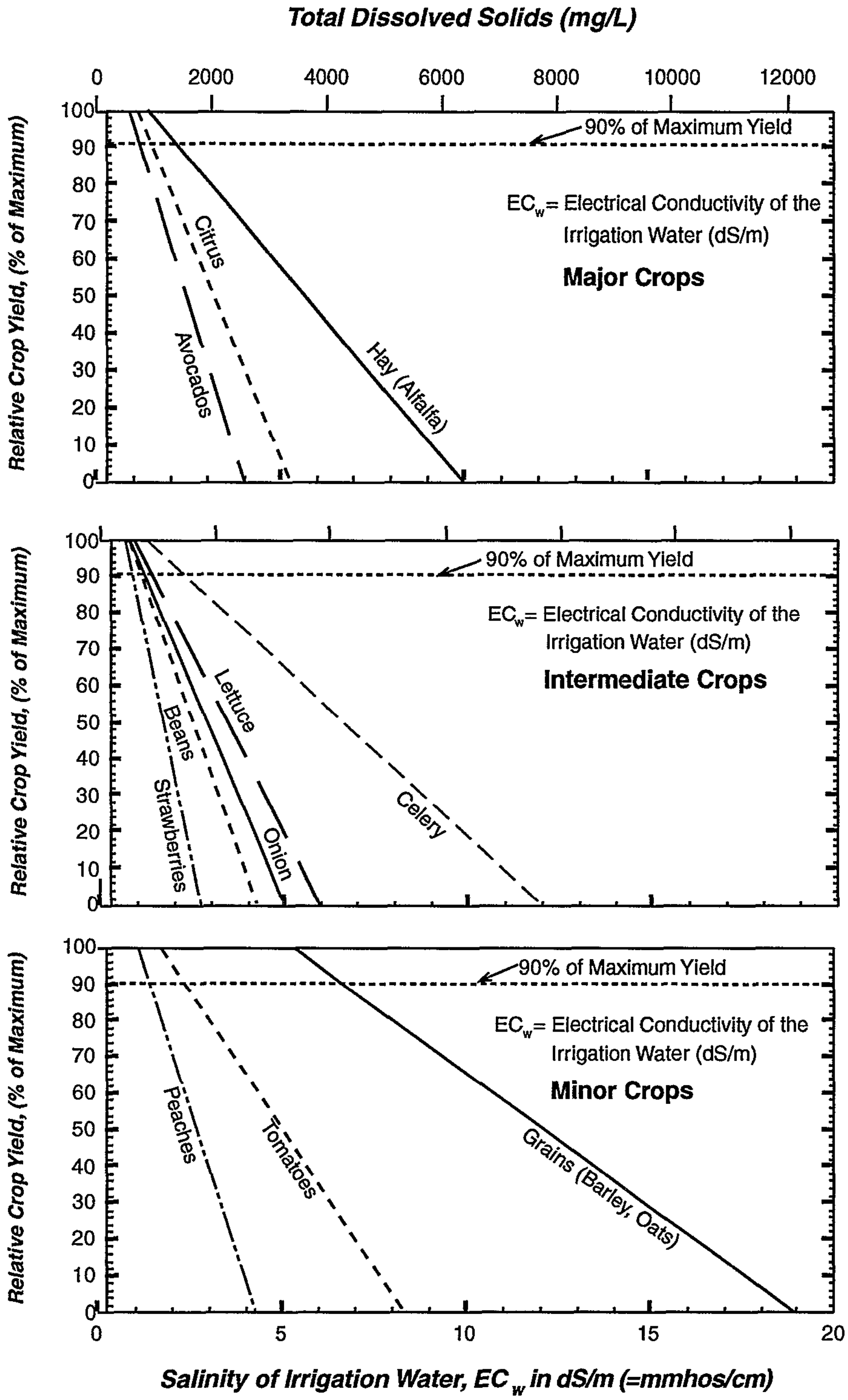
CALFED BAY-DELTA PROGRAM



Source:
Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

FIGURE 15
SOUTH COAST REGION YIELD POTENTIAL AS INFLUENCED BY IRRIGATION WATER SALINITY
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

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Table 4
Factors Affecting Selection of Irrigation Method Under Saline Conditions

Water Application Method	Application	Pattern of Salt Accumulation	Leaching Effectiveness	Special Considerations
Furrow	Row crops, soil with low to medium infiltration rate.	High in ridges between furrows, may increase in direction of slope if irrigations are non-uniform.	Effective leaching beneath furrow channels, salt left in ridges. Leaching requires more water than for methods with lighter, intermittent applications.	None.
Corrugation	Close-growing crops.	Leaves saltier strips between corrugation channels unless entire field surface is inundated.	Similar to furrow above.	None.
Border dike	Close-growing crops.	Leaves salt in dikes that separate borders.	Areas between dikes leached uniformly, but more water required than for light, intermittent, applications.	None.
Sprinkle: set	Most crops, all but very fine-textured soils.	No salt concentrations in root zone if system is designed and managed properly.	Uniform leaching, Can be used to leach salt accumulations left by other irrigation methods.	May encourage disease in sensitive crops, e.g., beans. Salty irrigation water may leave harmful deposits on leaves.
Sprinkle: mobile	Most crops, except trees and vines. Can be used to irrigate fields on rolling topography.	No salt concentrations in root zone if system is designed and managed properly.	Uniform leaching. Same as for set sprinklers, above.	None.
Micro-irrigation (Drip, trickle, sub-irrigation)	Because of high initial costs, used mostly for high-value crops or crops with high irrigation labor costs.	Salt concentrations at outer fringes of the soil mass wetted by each emitter.	Soil mass wetted by each emitter is well-leached. Difficult to leach all soil to depth of root zone.	When automated for light, frequent irrigations, saline water can be used, because low matric stress compensates (dry soil) for osmotic stress.
Source: Tanji, K. K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No.71.				

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Detailed discussions of various management practices to control soil salinity follow:

- **Additional Leaching**- Salts leached from the upper root zone accumulate to some extent in the lower part, but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, more active part of the root zone and long-term leaching is accomplished.

- **More Frequent Irrigation Events**- Salts concentrate in the soil profile as water is consumed by the crop. Hence, salt concentrations are lowest following an irrigation event and typically highest before the next irrigation event. Increasing irrigation frequency has historically been considered favorable under saline conditions. However, recent research at the University of California, Davis (Hanson, 1993), suggest the benefits of this management option may be overrated. The studies suggest that, just as under low-salinity conditions, scheduling should be based solely on soil moisture depletion. But because high salinity levels reduce yield, crop evapotranspiration will also be reduced. Therefore, over a given time period, soil moisture depletion will be lower under saline conditions than under non-saline conditions. The value of this management practice will need to be considered in relation to the economic impact of probable yield reduction.

- **Crop Selection**- When using saline irrigation water, selection of a salt-tolerant crop may be required to avoid potential reductions in crop yield. There is an approximate tenfold range in salt tolerance of agricultural crops, as illustrated in part by Figures 11 through 15, for crops in the California hydrologic regions of interest. The selection of a more salt-tolerant crop, however, will not eliminate the need for leaching and for careful management. It makes economic sense that agronomic areas will be dominated by the highest value crops that can be grown under existing conditions with the available irrigation water.

- **Changing or Blending Water Supplies**- Changing water supplies is a simple but drastic solution to a problem and is feasible only if an alternative, superior supply is available. Blending of waters may offer an overall improvement in quality and reduce a toxicity problem; however, blending of water supplies for salinity control is not a common practice. Most users alternate between supplies and attempt to use the lower quality water late in the growing season. Overall crop water use needs to be considered when changing, blending, or alternating water supplies for toxicity management. Safety factors for blending of water and in-field variability in irrigation and drainage conditions should also be considered.

Specific Ions

Unlike general salinity, which influences crops by reducing water availability, specific ions become problems when present at relative or absolute levels that are toxic to crops or that impact soil physical properties. Toxicity normally results when ions concentrate in the soil are absorbed by and accumulate in plant tissues. Crop sensitivity depends on the nature of the crop (species, cultivar, growth stage), ionic concentrations, and soil and weather conditions. Effects on soils occur when soil chemical conditions become imbalanced, favoring adverse changes in soil physical properties. Soil properties such as texture and existing chemistry strongly influence the effect specific ions may have. Ions that commonly cause plant-growth or soil problems are chloride, sodium (sodium adsorption ratio, or SAR), and boron.

The effects, rationale for the inclusion of each specific ion, and management techniques are presented below.

Chloride

The most common toxic ion encountered in irrigation water supplies is chloride. Chloride is adsorbed (or retained) only slightly on soil particles. It therefore moves readily with the soil water and is taken up by the crop, accumulating in the leaves during transpiration. At toxic levels, injury symptoms develop such as leaf burning and desiccation. Continued uptake can lead to necrosis (dead tissue) and is often accompanied by early leaf drop or defoliation. Plant tissue analysis is typically used to confirm chloride toxicity.

Uptake of chloride depends on relationship between the ability of the crop to exclude chloride, and concentrations in the soil water. Soil-water concentrations are controlled by concentrations in irrigation water and the amount of leaching that occurs. Crop tolerance of chloride is not as well documented as crop tolerance of salinity, and quantitative yield reduction relationships have not been defined. However, in general, woody plants, such as California's fruit and nut crops, tend to be more sensitive to chloride.

Crops grown under overhead sprinkler irrigation can take up chloride through foliar adsorption of irrigation water into leaves during and after irrigation events. Management practices to avoid or minimize foliar uptake are discussed below, in the "Management" section.

Criteria

The sensitivity of crops grown in areas served from the Delta dictate agricultural chloride criteria for the Delta. Figure 11 and Table 3 summarize the geographic area and crop mix, as previously discussed. If the most sensitive crops are considered, chloride toxicity symptoms occur when leaves accumulate from 0.3 to 1.0 percent chloride on a dry-weight basis, but sensitivity varies among these crops. Many tree crops can begin to show injury above 0.3 percent chloride (dry weight). In some cases, the osmotic threshold may be exceeded and the yield decreased without obvious injury. Toxicity due to wetting of leaves by sprinkling has occurred on sensitive crops with water at concentrations as low as 3 meq/L of chloride (Ayers and Westcot, 1985).

Most of the data on salt tolerance were obtained in fields salinized with chloride salts of Na^+ and Ca^{2+}, so they can be converted to express tolerances in terms of chloride concentration. If chloride is the predominant anion in the soil solution, then the concentration of chloride, denoted by $[Cl^-]$, can be estimated from the electrical conductivity by the following relationship:

$$[Cl^-] = 10 \times EC_e,$$

where: $[Cl^-]$ is expressed in mol/m^3 and EC in dS/m (USSL, 1954).

Management

The major objectives in selecting management practices are to control chloride uptake and toxicity and to maintain production. The potentially toxic excess chloride can be reduced through various management practices:

- Additional leaching in a manner similar to that for salinity.
- More frequent irrigation.
- Selection of a more tolerant crop. Selection of tolerant rootstocks or cultivars is another method of coping with existing conditions. Rootstocks or varieties differ in their ability to exclude ions such as chloride. Tolerant clones/varieties produce good crops under less than ideal conditions.
- Blending water supplies may offer an overall improvement in quality and reduce the potential toxicity problem. Alternating water supplies, in lieu of blending, is more typical and can be more cost effective.

Where foliar absorption or deposition is a problem, certain management practices have been successful in minimizing effects. Some practices may require minor changes in management, while others will require more elaborate and costly changes. Some of these practices are:

- Irrigation events scheduled at night.
- Avoiding irrigation during periods of high wind to minimize evaporative concentration in droplets and on leaves.

- Control sprinkler drift impacts by moving sprinkling progressively downwind instead of upwind in order to wash away drifted salts as soon as possible.
- Increase sprinkler rotation speeds to minimize drying on the leaves between rotations.
- Increase the rate of application to minimize the total period of crop wetting.
- Increase droplet size.
- Change the crop (an extreme alternative).

Boron

Surface waters do not usually contain boron at toxic levels. Groundwater from wells or springs can contain toxic levels, especially near geothermal areas and earthquake faults. Some areas near the Delta are underlain by groundwater with high levels of boron. The average concentration in seawater is reported as 4.5 mg/L in the form of borate (EPA, 1976). Historic concentrations of boron at monitored sites in the Delta are presented later in this report.

Boron is essential in relatively small quantities for optimum plant growth, however, minimal exceedance of the desirable limit can be lead toxicity. Boron toxicity can affect almost all agronomic crops and, like salinity, there is a wide range of tolerance among crops. Climatic and soil conditions also influence boron toxicity, with boron uptake being generally higher at lower soil pH. The first symptoms are normally yellowing or spotting of older leaves, and/or drying of the leaf tips and edges (leaf burn). Drying and chlorosis can progress from the edges towards the center of the leaf, and become more severe with prolonged exposure (Tanji, 1990). Seriously affected tree crops may not show typical leaf symptoms, but may exhibit twig die-back and develop a gum layer on limbs and trunks.

Criteria

The crops grown in areas served from the Delta dictate agricultural boron criteria for the Delta. The limits presented in the water quality guidelines are not based on plant symptoms, but upon an expected, significant loss in yield if the boron value is exceeded. Sensitive crops have shown toxic effects at and below 1 mg/L (Ayers and Westcot, 1985). Table 5 presents the allowable maximum boron concentrations in irrigation water for some crops grown in the study area in California.

Table 5
Tolerable Concentrations of Boron in Irrigation Water

Crop	Boron (mg/L)

Table 5 Tolerable Concentrations of Boron in Irrigation Water	
Cotton	6.0 to 15.0
Alfalfa	4.0 to 6.0
Sugar Beets	4.0 to 6.0
Tomatoes	4.0 to 6.0
Barley	2.0 to 4.0
Corn	2.0 to 4.0
Cantaloupe	2.0 to 4.0
Orange	0.5 to 0.75
Grapes	0.5 to 0.75
Peaches	0.5 to 0.75
Plums	0.5 to 0.75
Wheat	0.75 to 1.0
Beans	0.7 to 1.0
Lemons	<0.5

Management

The major objective in selecting management practices is to control boron uptake and toxicity, and to maintain production. Boron concentrations can be reduced by various management practices similar to those previously discussed for chloride.Reclaiming boron-affected soils requires leaching the boron from the root zone. Because boron mobility is reduced by adsorption on soil particles, removing it from the soil profile requires approximately two to three times more leaching water than is typically required for reclaiming saline soils (Hanson, 1993). Leaf absorption under sprinkle irrigation is not a problem with boron.

SAR (Sodium)

Sodium hazards in irrigation and soil waters can impair crop production. Unlike salinity, excessive sodium does not curtail the uptake of water by plants, but rather destroys soil structure and reduces the infiltration of water into the soil. Thus, plant growth can be affected by drought stress or lack of aeration. When calcium and magnesium are the predominant cations adsorbed on soil particles, the soil tends to have a granular structure that is easily tilled and readily permeable. Unbalanced by other cations, large amounts of sodium can disperse soil particles, so that soil structure breaks down and hydraulic conductivity decreases. Good soil structure and adequate drainage are essential for sustainable soil and salinity management, and must therefore, be maintained. Additional agronomic issues arising from excess sodium include soil crusting (especially over seedbeds), temporary saturation of the soil surface layer, and/or related disease, weed, root-respiratory, and nutritional problems. In extreme cases and for sensitive plants, sodium ions can be phytotoxic, much in the same manner as chloride.

The exchangeable sodium percentage (ESP) of soil extracts is generally a good indicator of the exchangeable sodium status within the soil. The sodium adsorption ratio (SAR) relates sodium, calcium, and magnesium concentrations in water. In combination with the EC of the water, SAR indicates the water's tendency to disperse soil.

Criteria

The sensitivity of crops grown in areas served by the Delta dictate agricultural sodium criteria for the Delta. Criteria for SAR are evaluated based on the EC of irrigation water being used, and are shown in Table 2. These criteria are for soil dispersion. In general, a given, relative concentration of sodium has less impact in saltier water. The specific ion toxicity guidelines (Table 2) address the potential for the sodium toxicity after irrigation.

Management

Management of sodium by leaching alone can be impractical because of problems with soil aeration and drainage. Sodium is generally managed by replacement with calcium through the addition of gypsum, or sulfuric acid, which reacts with soil calcium carbonate, to liberate calcium. These treatments must be followed by leaching with water of acceptable quality. In general, the benefit of a water-applied amendment is much greater when the irrigation water salinity is relatively low. Field trials can be used to determine whether water or soil amendments improve water penetration or yield to an extent that justifies the cost.

Direct soil calcium amendments include:

- Calcium chloride and calcium nitrate (highly soluble and have little effect on pH).
- Gypsum (relatively cheap, has little effect on pH, and is the most commonly used amendment).
- Calcium/magnesium carbonate (often preferred where soil pH is less than 7.2).

Indirect calcium suppliers:

- Sulfuric acid/urea-sulfuric acid (react with lime to form gypsum); rapid and can reduce soil pH).

- Sulfur, lime-sulfur, Nitro-sul (slower reacting and require a warm, well-aerated soil).

- Polymers/organic acids (react with calcium-carbonate in the soil to supply calcium).

pH

The sensitivity of crops and soils in areas served from the Delta dictate agricultural pH criteria for the Delta. The pH of irrigation water is not normally a critical parameter. Compared with the large buffering capacity of the soil matrix, the pH of applied water is rapidly changed to approximately that of the soil. The greatest direct hazard of this parameter is related to potential corrosion of or plugging of irrigation equipment (such as aluminum pipe and drip emitters, respectively) and precipitation of residues on plants (such as cut flowers in greenhouses). Nutritional imbalance can be caused by irrigation water with a pH outside of the normal range.

Criteria

To avoid undesirable effects in irrigation waters, the pH should be between 6.5 and 8.4. Low salinity water ($EC_w < 0.2$ dS/m) sometimes has a pH outside the normal range and normally causes few problems for crops; however, this type of water may rapidly corrode pipelines, sprinklers, and related irrigation equipment.

Management

Any change in soil pH caused by the water will take place slowly since the soil is very strongly buffered and resists change. Corrective adjustments of water pH with amendments is usually practical only under special circumstances. It is usually easier to correct the soil pH periodically with amendments like sulfur (to acidify) or calcium carbonate (to raise the pH).

Turbidity

Turbidity is a measure of "suspended and settle-able solids" and is descriptive of the organic and inorganic particulate matter in water. Effects of turbidity on plants and soils include the formation of crusts at the soil surface (which can inhibit water infiltration and aeration, impede seedling emergence, and hinder leaching of saline soils), and the formation of films on plant leaves (blocking sunlight and reducing photosynthesis and marketability). High colloidal content in water used for sprinkler irrigation can result in deposition of films on leafy vegetable crops such as lettuce, which affects marketability and management.

Another impact of turbid water on irrigation practices is on the conveyance and delivery of water for crop production. Settleable matter in the water can prematurely decrease reservoir

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capacity, and increase maintenance requirements on delivery canals due to siltation. Further, turbidity increases wear on pumping facilities.

Criteria

The irrigation and conveyance systems for crops grown in areas served by the Delta dictate agricultural turbidity criteria for the Delta. Available literature does not provide adequate data to establish specific turbidity recommendations for irrigation waters. Therefore, no specific recommendations are made at this time. The only related criteria listed in Table 2 apply to surface water bodies and address increases in turbidity that result from controllable water quality factors. These criteria are summarized in Table 6 and are superseded by any change in turbidity that adversely affects beneficial uses of surface waters.

Table 6
Controllable Turbidity Criteria

Natural Turbidity	Maximum Increase
0 - 50 NTU	20 %
50 - 100 NTU	10 NTU
Greater than 100 NTU	10 %

Source:CRWQCB Santa Ana Region. 1995. Santa Ana River Basin (8), Water Quality Control Plan.

Management

Source control is the best management tool for control of turbidity in the water supply. This would consist of limiting sediment loading to irrigation water supplies by controlling erosion on the landscape, especially during intense storm events. As agricultural lands in the Sacramento and San Joaquin valleys continue to be irrigated with low-volume irrigation systems like drip and micro-sprinkle, clogging, maintenance, and on-farm water management (filtration) requirements will need to be considered when selecting a new system or evaluating water supply. Filtration and maintenance requirements for turbid water for low-volume irrigation can be costly and may make the water unusable.

Nutrients

Nutrients in irrigation water supplies can provide fertilizer for crop or landscape production, but in certain instances when nutrient loads exceed plant needs they can cause agronomic problems. Excessive vegetative growth, reduced yields, delayed or uneven maturity, or reduced quality are some of the potential impacts of excess nutrients (especially, nitrogen). Algal growth stimulated by excess nutrients can increase facilities maintenance costs. In extreme cases, irrigation equipment for sprinkle and drip irrigation can plug, increasing maintenance costs.

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Criteria

The crops grown in areas served by the Delta dictate agricultural nutrient criteria for the Delta. Criteria for nitrate are shown in Table 2. (Criteria for ammonium are not shown). However, ammonium-N concentrations can simply be added to nitrate-N concentrations, then the sum of the two can be considered relative to the nitrate-N criteria. Sensitive crops may be affected by nitrogen concentrations above 5 mg/L. Most other crops are relatively unaffected until nitrogen exceeds 30 mg/L. Concentrations below 5 mg/L usually have little effect, even on sensitive crops, but may stimulate algal and aquatic-plant growth.

Management

Source control can, to some extent, control nutrient concentrations in the water supply. Principal nutrient sources include agriculture (confined animal waste, fertilizer), point and nonpoint source flows from municipal and industrial sources (POTW outfalls, industrial outfalls, and runoff from land surfaces). When nutrient concentrations in irrigation water are high, soil and plant tissue monitoring may help the farmer manage the problem. In extreme cases, sensitive crops may require an alternative or blended water supply, or may not be grown. Alternative, more tolerant crops grown, but other water quality parameters, land suitability and market conditions dictate crop selection.

Temperature

Much of California's irrigation water originates in the mountains as snowmelt. It can still be cold when it is delivered to agricultural fields, especially in the vicinity of major reservoirs (e.g., Lake Oroville and Thermolito Afterbay). This can cause problems for crop production because the temperature of irrigation water has direct and indirect effect on plant growth. Each occurs when physiological functions are impaired by excessively high or excessively low temperatures. The direct effects on plant growth from extreme temperature of the irrigation water occurs when the water is first applied, and they are less pronounced with pressure irrigation systems than with surface irrigation systems. Indirect effects of the temperature of irrigation water on plant growth occur as a result of the water's influence on soil temperature. Temperature effects are primarily related to rice seedling emergence and crop development. Rice production is concentrated in the northern San Joaquin and southern Sacramento valleys, as shown in Figure 16.

Criteria

Water temperatures between 77 and 90 degrees F favor rice stand establishment (University of California, Davis, 1983). Water is frequently outside of this range near reservoirs, but this situation is not directly influenced by Delta water management.

Management

When water is colder, irrigation facilities that spread water out for solar warming can be used, including shallow reservoirs and flooded fields. Some rice farms designate an upper part of the field for spreading and warming water, or else they accept lower productivity in parts of their farm that receive irrigation water directly from the canal.

Location of Critical Level Consideration

This section discusses the location at which water quality criteria for agricultural water supply ought to be applied. As described previously, this is really at the headgate of every field, since that is where the water is used, and water quality can change as it is conveyed to a field. However, such an application of criteria could never be compared with historical data, nor could the performance of the water system at so many locations be realistically monitored. Therefore, a number of historical monitoring points were identified to provide a general picture of historical water quality at strategic points in the water delivery system. Water quality monitoring stations were strategically identified within the geographic scope of agricultural water use related to the Delta, including tributary areas, and areas whose water supply passes through the Delta. These stations are, or have been points of historical sampling under various completed and ongoing monitoring programs, and under the direction of a multitude of agencies. Data collected at Delta stations have been used to help provide a more complete picture of water quality changes according to changing seasons and hydrologic conditions. The location for nine water quality monitoring stations within the Delta area are depicted in Figure 17, with the remaining five stations depicted in Figure 18. The 13 water quality monitoring stations identified, and the rationale for critical level sampling are summarized in Table 7.

In general, the stations were identified by the Agricultural Water Quality Subteam to represent significant points in the agricultural water supply delivery system, including strategic points within and beyond the Delta.

Reference is made to the flow schematic inset on Figure 19, which also depicts proposed water quality monitoring stations south of the Delta. The California Aqueduct (Cal-Aq) and the Delta-Mendota Canal (DMC) headworks are at the Banks and Tracy pumping plant (PP) stations, respectively. The open channel conveyance for these two facilities are approximately

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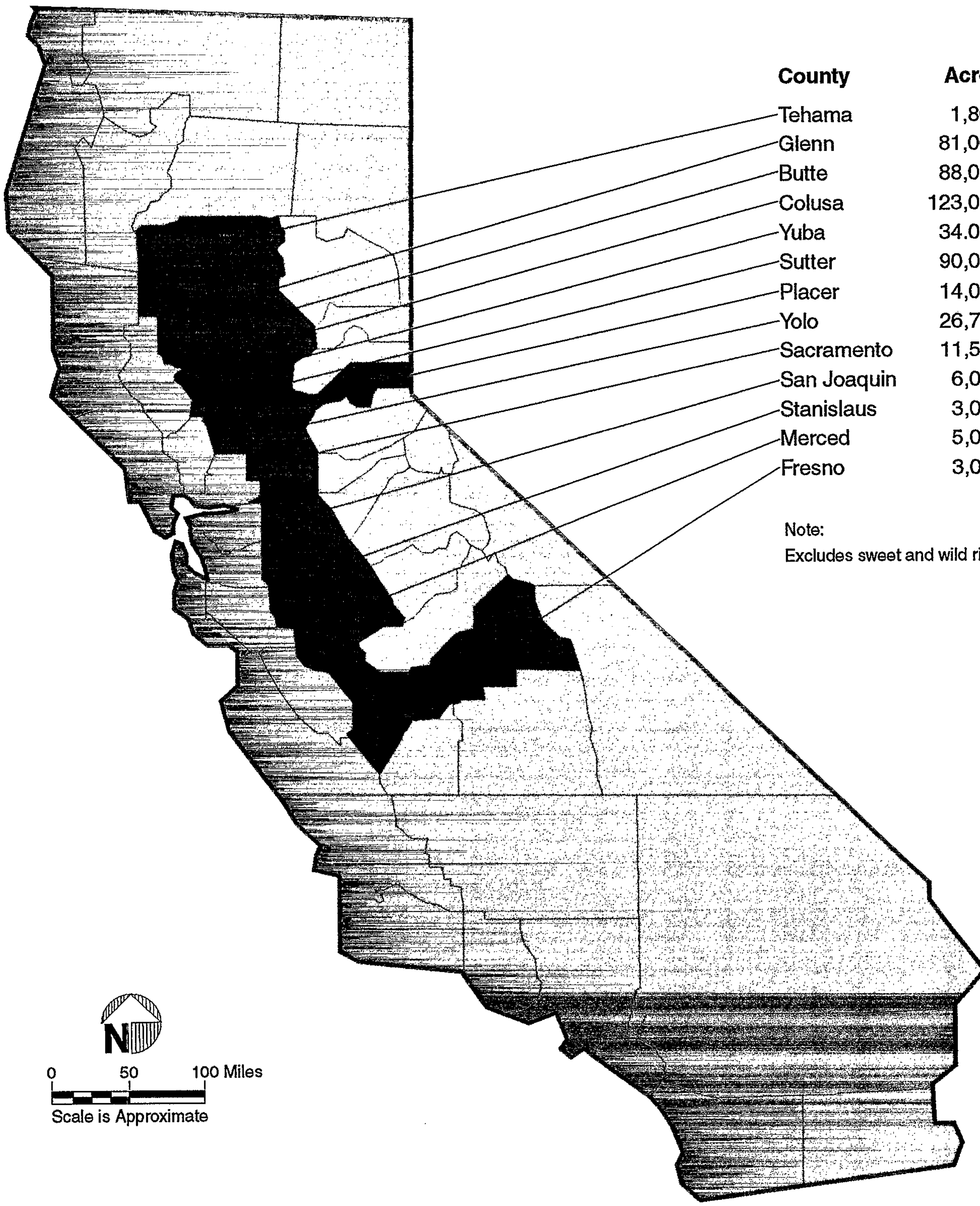

County	Acres
Tehama	1,800
Glenn	81,000
Butte	88,000
Colusa	123,000
Yuba	34.000
Sutter	90,000
Placer	14,000
Yolo	26,700
Sacramento	11,500
San Joaquin	6,000
Stanislaus	3,000
Merced	5,000
Fresno	3,000

Note:
Excludes sweet and wild rice.

Source: California Agricultural Statistics Service, 1994

FIGURE 16
DISTRIBUTION OF RICE ACREAGE IN CALIFORNIA BY COUNTY
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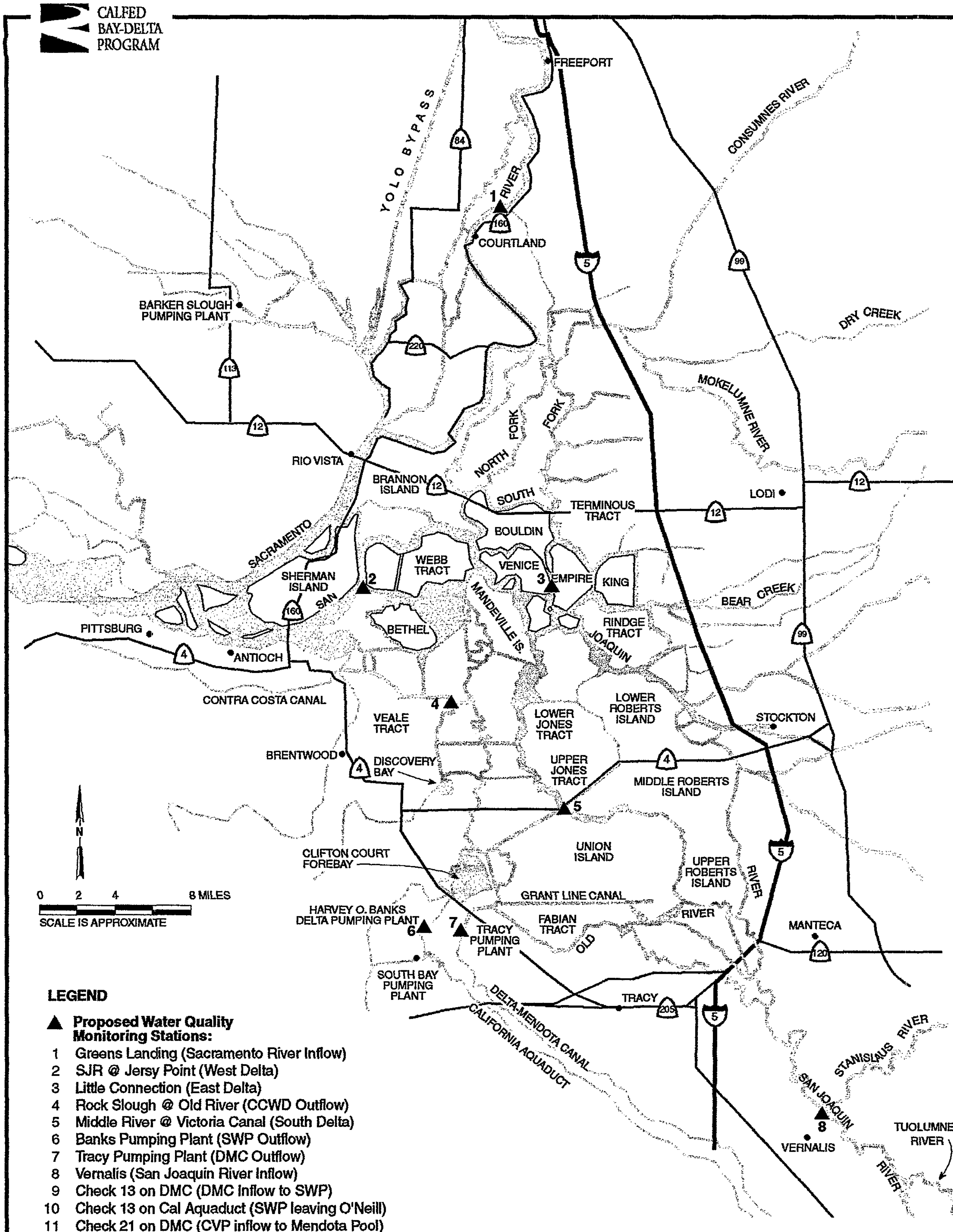
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

2120_015



LEGEND

▲ **Proposed Water Quality Monitoring Stations:**

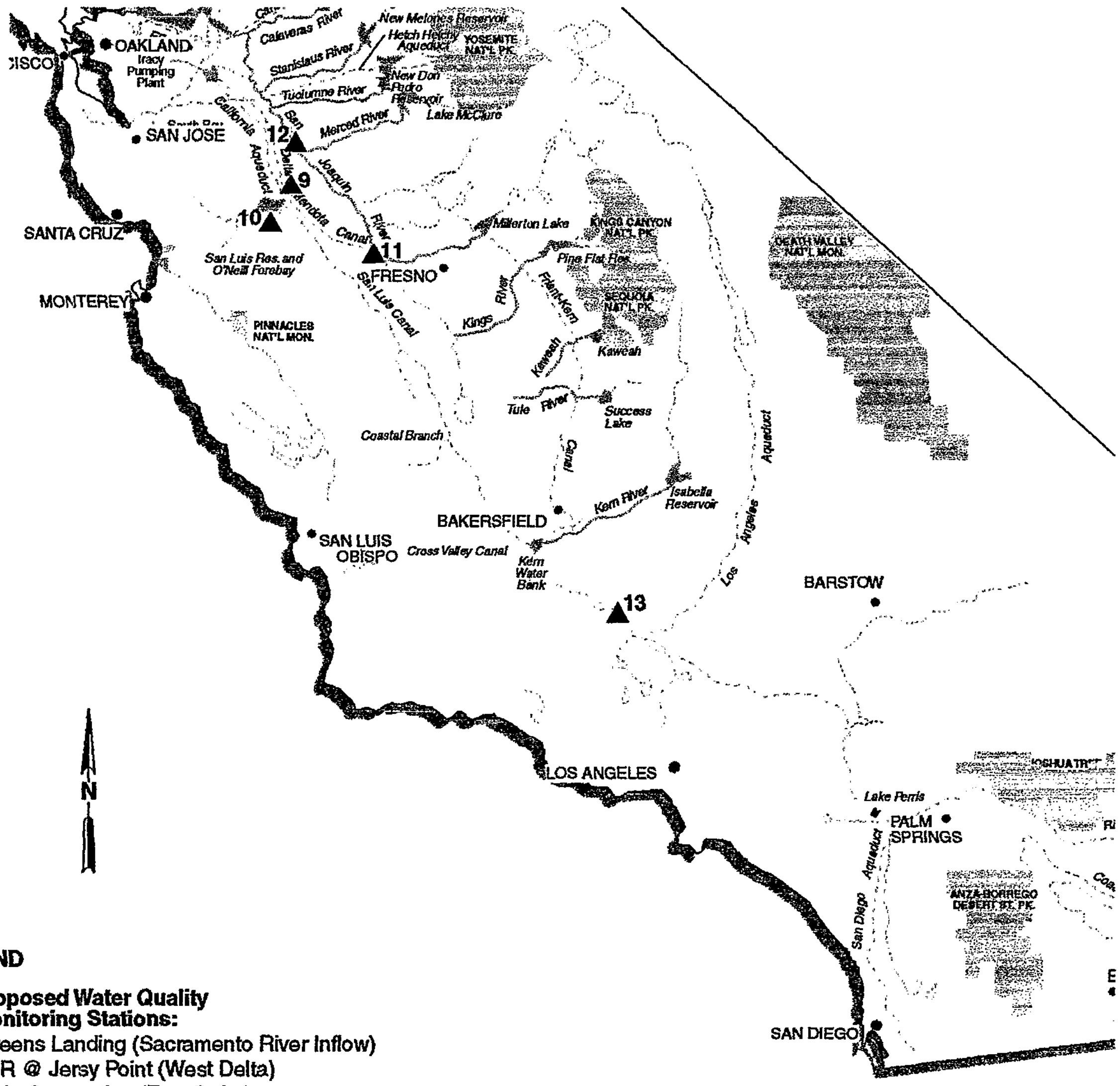
1 Greens Landing (Sacramento River Inflow)
2 SJR @ Jersy Point (West Delta)
3 Little Connection (East Delta)
4 Rock Slough @ Old River (CCWD Outflow)
5 Middle River @ Victoria Canal (South Delta)
6 Banks Pumping Plant (SWP Outflow)
7 Tracy Pumping Plant (DMC Outflow)
8 Vernalis (San Joaquin River Inflow)
9 Check 13 on DMC (DMC Inflow to SWP)
10 Check 13 on Cal Aquaduct (SWP leaving O'Neill)
11 Check 21 on DMC (CVP inflow to Mendota Pool)
12 Crows Landing (San Joaquin River upstream)
13 Edmonston Check 41(Outflow to South Coast)

NOTE
Stations 9 through 13 not depicted

SOURCE:
SACRAMENTO-SAN JOAQUIN DELTA ATLAS
DWR, 1995

2120_115

FIGURE 17
PROPOSED WATER QUALITY MONITORING STATIONS
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT



LEGEND

▲ **Proposed Water Quality Monitoring Stations:**

1 Greens Landing (Sacramento River Inflow)
2 SJR @ Jersy Point (West Delta)
3 Little Connection (East Delta)
4 Rock Slough @ Old River (CCWD Outflow)
5 Middle River @ Victoria Canal (South Delta)
6 Banks Pumping Plant (SWP Outflow)
7 Tracy Pumping Plant (DMC Outflow)
8 Vernalis (San Joaquin River Inflow)
9 Check 13 on DMC (DMC Inflow to SWP)
10 Check 13 on Cal Aquaduct (SWP leaving O'Neill)
11 Check 21 on DMC (CVP inflow to Mendota Pool)
12 Crows Landing (San Joaquin River upstream)
13 Edmonston Check 41(Outflow to South Coast)

Major Central Valley Rivers and Associated Reservoirs

Other Rivers and Reservoirs

Major Conveyance Facilities

NOTE
Stations 1 through 8 not depicted

SOURCE:
CH2MHILL
USBR
DWR

FIGURE 18
PROPOSED WATER QUALITY MONITORING STATIONS SOUTH OF THE DELTA
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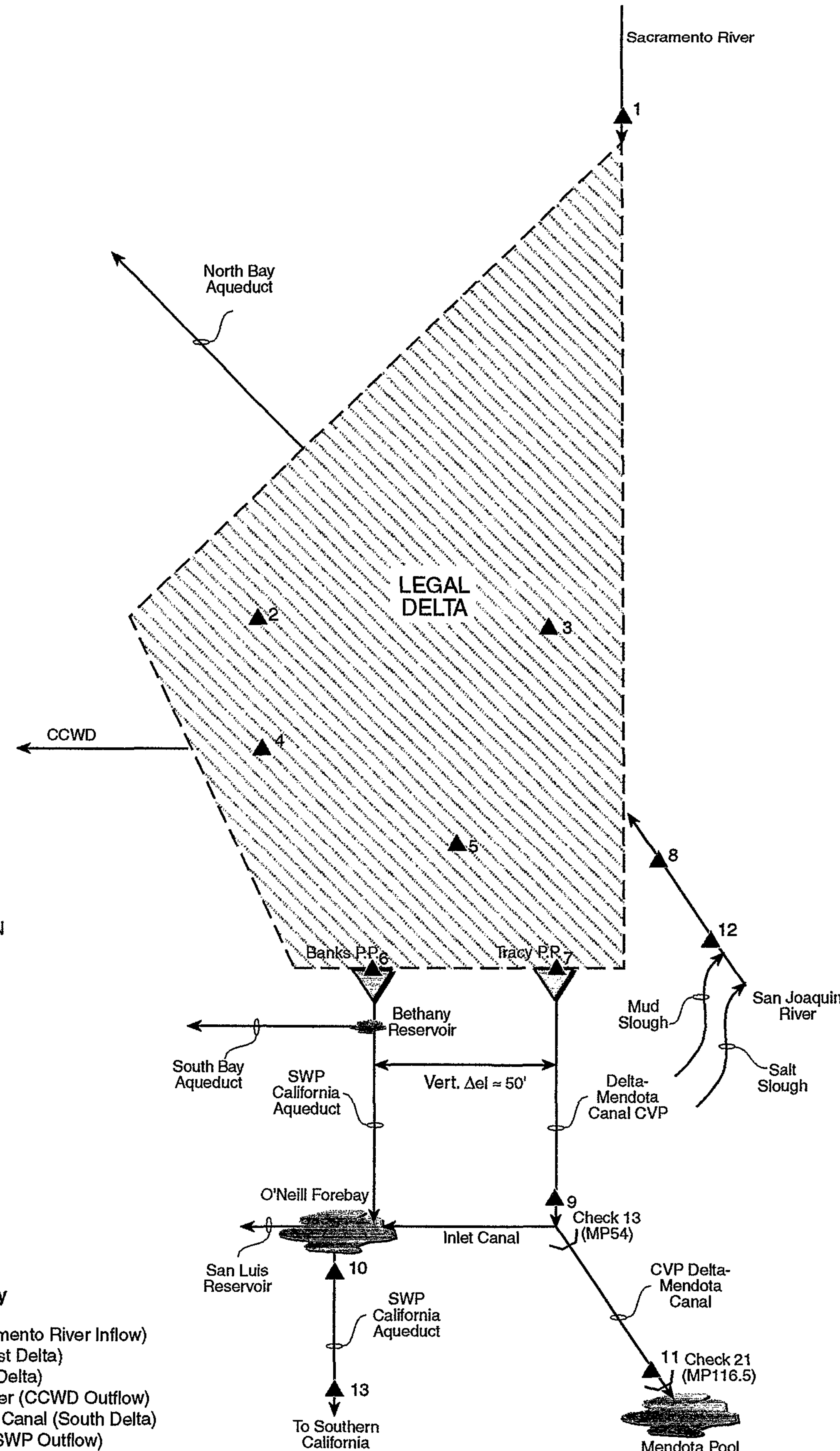
CALFED BAY-DELTA PROGRAM



SOURCE:
SACRAMENTO-SAN JOAQUIN DELTA ATLAS
DWR, 1995
USBR
DWR

LEGEND

▲ **Proposed Water Quality Monitoring Stations:**

1. Greens Landing (Sacramento River Inflow)
2. SJR @ Jersy Point (West Delta)
3. Little Connection (East Delta)
4. Rock Slough @ Old River (CCWD Outflow)
5. Middle River @ Victoria Canal (South Delta)
6. Banks Pumping Plant (SWP Outflow)
7. Tracy Pumping Plant (DMC Outflow)
8. Vernalis (San Joaquin River Inflow)
9. Check 13 on DMC (DMC Inflow to SWP)
10. Check 13 on Cal Aquaduct (SWP leaving O'Neill)
11. Check 21 on DMC (CVP inflow to Mendota Pool)
12. Crows Landing (San Joaquin River upstream)
13. Edmonston Check 41(Outflow to South Coast)

2120_03

FIGURE 19
WATER QUALITY MONITORING STATION FLOW SCHEMATIC
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50 feet vertically offset downstream of their headworks, with the DMC on the downslope side. Between the Tracy PP and the O'Neill Forebay, there are inflows into the DMC from multiple sources that can affect the overall water quality in the canal. These sources include groundwater wells, ephemeral creeks that flow into the DMC, and tailwater from lands on the upslope side. Therefore, Check 13 located at MP 75 on the DMC just downstream of the Inlet Canal to the O'Neill Forebay, will provide changes in water quality from these inputs, as well as that entering the O'Neill Forebay before co-mingling of flows. Between Check 13 and the Delta-Mendota Pool (DMP), there are additional inflows to the DMC, and the water quality influence is more pronounced in this reach of canal. Particularly in wet years temporary lakes form on the upslope side of the canal. These drain into the canal, influencing the quality of water flowing into the DMP. Check 21 located at MP 116.5 on the DMC just upstream of the DMP inlet, will provide an indication of changes in water quality from these inputs, as well as that entering the DMP.

Table 7
Water Quality Monitoring Stations

Sta.	Station Name	Station Location	Rationale
1	GREENES	Sacramento River at Greenes Landing	Sacramento River inflow quality
2	SJRJERSEY	San Joaquin River at Jersey Point	Western Delta water quality
3	LCONNECT	Little Connection Slough at Empire Tract	San Joaquin River quality down- stream of Mokelumne Inflow
4	ROCKSL	Rock Slough at Old River	CCWD & BBID service water quality
5	MIDDLER	Middle River at Borden Hwy	South Delta water quality
6	BANKS	Delta SWP P.P. headworks	SWP Delta export quality
7	DMC	DMC Intake at Lindemann Road	CVP Delta export quality
8	VERNALIS	San Joaquin River at Vernalis	San Joaquin River Delta Inflow quality
9	O'NEILL	DMC turnout at inlet canal to O'Neill Forebay	DMC inflow quality to SWP
10	CHECK13	CA Aqueduct, Check 13 at O'Neill Outlet	SWP water quality leaving O'Neill Forebay
11	CHECK21	Check 21 at mp 116.5 at inlet to Mendota Pool	CVP water quality arriving at Mendota Pool
12	CROWS	San Joaquin River at Crows Landing	San Joaquin River upstream of Delta water quality
13	EDMONSTON	Check 41 at Tehachapi Control Structure SWP	SWP export water quality to Southern California

Source: CALFED Bay-Delta Agricultural Water Quality Sub-Team. January 1997. Draft Report.

SWP flows serving the South Coast Hydrologic Region, through the Edmonston Pumping Plant (EPP). Monitoring at Check 41 (located upstream of the Tehachapi Control Structure bifurcation, and downstream of the (EPP) will reflect the effects of such factors as groundwater integration via the Kern Water Bank, and inflow from southern tributaries.

Timing of Critical Level Consideration

The timing of critical-level consideration for water quality criteria application should be year-round. This is because:

- Irrigation occurs year-round in much of the southern portion of the geographic scope for agricultural water quality criteria application.
- Pumping into San Luis Reservoir from the Delta occurs year-round, so Delta water quality at any time of year influence stored water quality (See Calendar of Pumping section).

However, poorest water quality is generally experienced during late summer and early fall, when flows are lowest (see Historical Water Quality Data section).

Calendar of Pumping

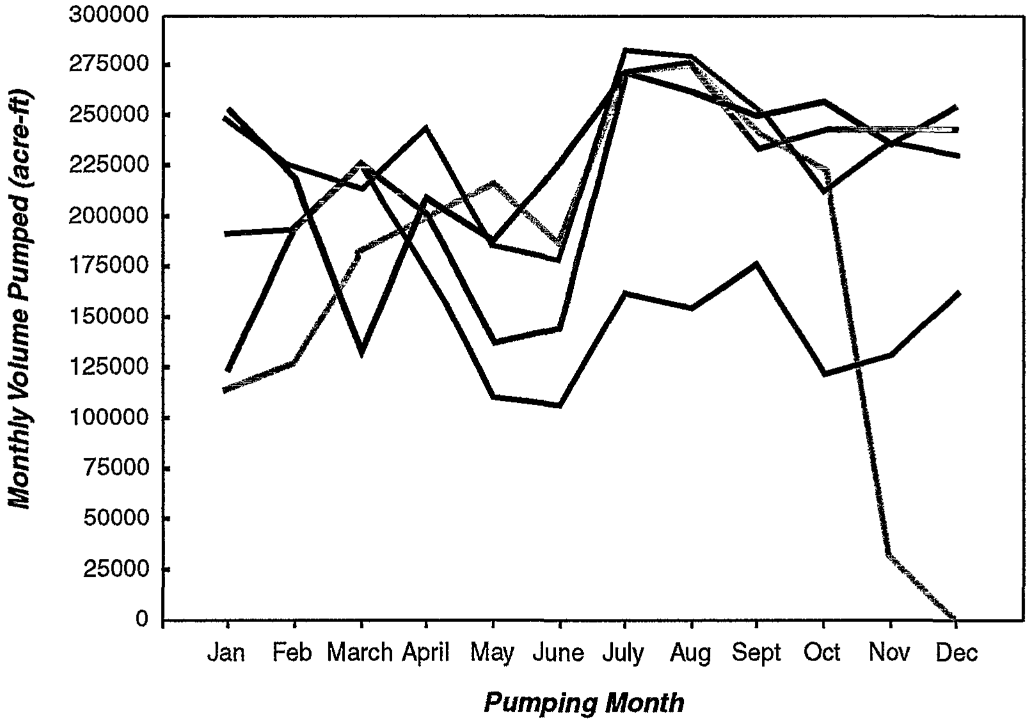
Historical records of pumping from the Delta to serve water users south of the Delta were obtained. The data can be used in conjunction with historical water quality data to assess timing of critical level consideration for irrigation water quality criteria. Historical monthly pumping at the Tracy Pumping Plant (TPP) of total DMC inflows by water year type for years 1985 to 1995, are presented in Figure 20. DWR 40-40-30 Water Year Classifications were used, and where two replicates of water year type were not represented, the next closest water year was pooled to provide a minimum of two years data per water year type. Pumping flows for the TPP reflect all pumping including any SWP (shared flows) that occur periodically.

Historical monthly pumping at the Banks Pumping Plant (BPP) of total SWP inflows by water-year type for 1985 to 1995, are presented in Figure 21, these flows reflect all pumping including any SWP (shared flows) that occur periodically. Figure 22 illustrates the division between Federal and CDWR historical co-mingled flows by water year type.

Historical Water Quality Data

Thirteen water quality monitoring stations were identified for their value as indicators of historic water quality at strategic points in the water delivery system. Available historical water quality data was compiled for the parameters of concern for the time period, 1985 - 1995. Table 8 is a summary of the stations, and respective agencies that provided data. The time frame was considered adequate, and representative of recent water quality trends at these locations in the water delivery system. It was desirable to obtain data for all the DWR 40-40-30 water-year-type classifications, however, only four of the five water year types are included in this time frame, with the below normal (BN) year type missing from the set.

Where data was not available for the complete time period, the subset of available data was used. In addition, data for all the parameters of concern were available at all stations.



SOURCE: USBR

NOTE:
Pumping flows reflect all pumping including any SWP (shared flows) that occur periodically. Pumping data is for years 1985 through 1995. Where two replicates of water year type were not represented in this time frame the next closest water year was pooled to provided a minimum of two years of data per water year type.

LEGEND

- Wet
- Above Normal
- Below Normal
- Dry
- Critically Dry

FIGURE 20
HISTORICAL MONTHLY TRACY PUMPING OF DELTA-MENDOTA CANAL INFLOWS BY WATER YEAR TYPE
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AGRICULTURAL WATER QUALITY SUBTEAM REPORT

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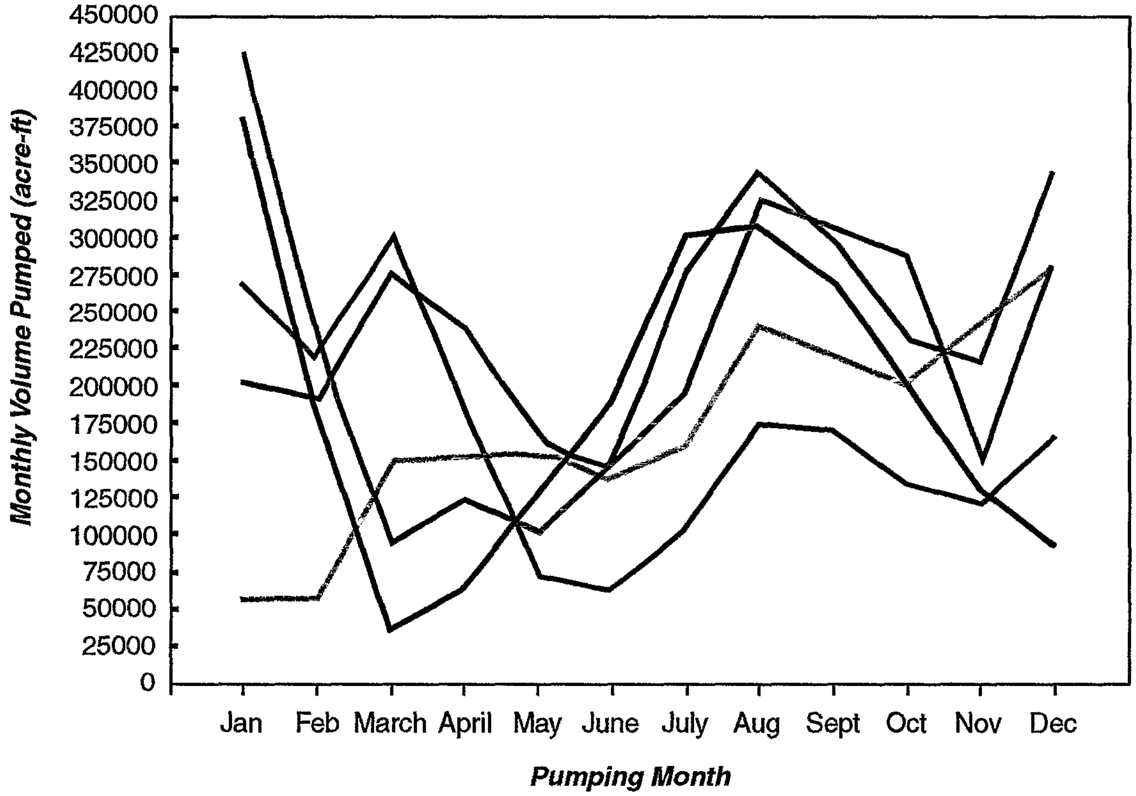
PROGRAM



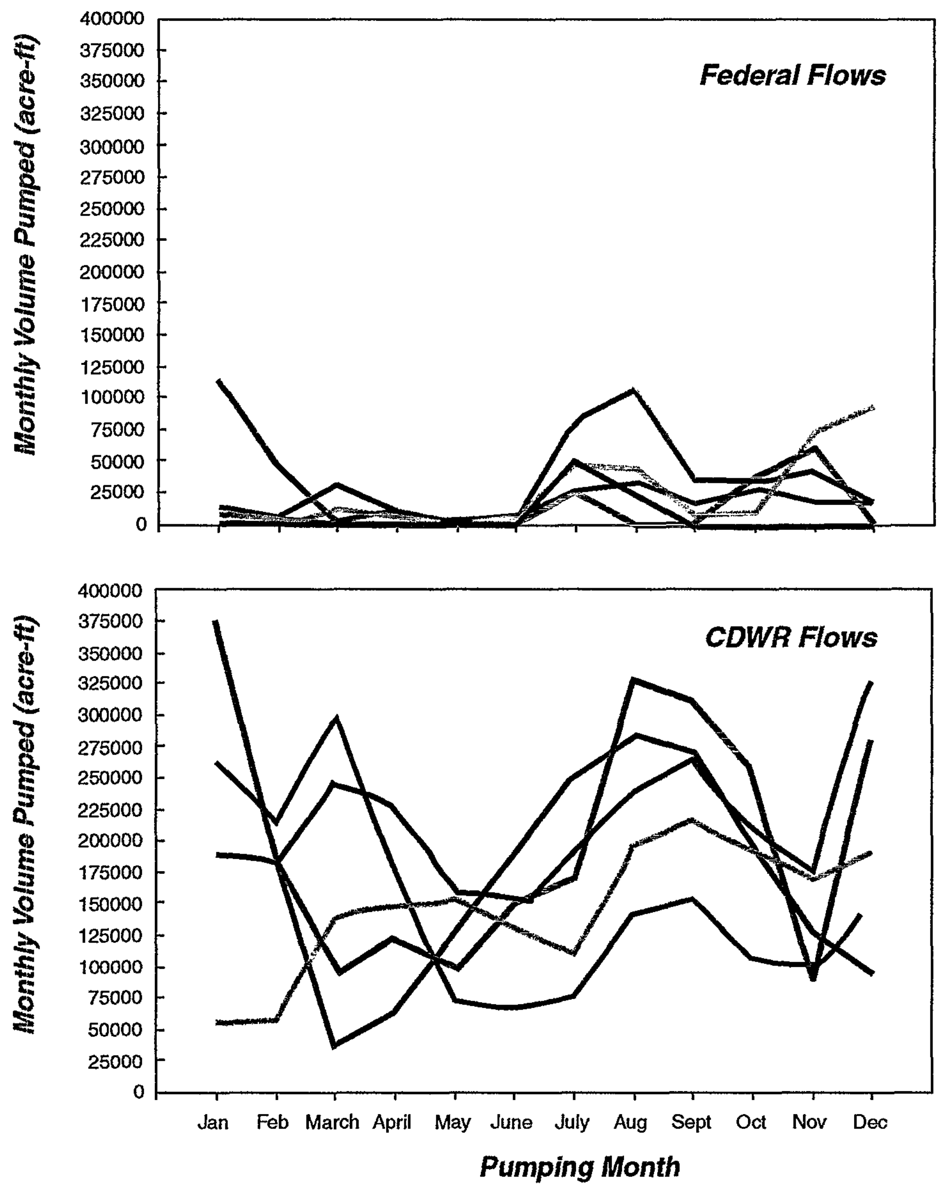
Source:DWR, 1996.
Note:
Pumping flows reflect all pumping including any SWP (shared flows) that occur periodically. Pumping data is for years 1985 through 1995. Where two replicates of water year type were not represented in this time frame the next closest water year was pooled to provided a minimum of two years of data per water year type.

LEGEND

- Wet
- Above Normal
- Below Normal
- Dry
- Critically Dry

FIGURE 21
HISTORICAL MONTHLY BANKS PUMPING OF TOTAL CALIFORNIA AQUEDUCT INFLOWS BY WATER YEAR TYPE
CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER QUALITY SUBTEAM REPORT

2120_012



SOURCE: DWR, 1996.

NOTE:
Pumping data is for years 1985 through 1995. Where two replicates of water year type were not represented in this time frame the next closest water year was pooled to provided a minimum of two years of data per water year type.

LEGEND

- Wet
- Above Normal
- Below Normal
- Dry
- Critically Dry

FIGURE 22
HISTORICAL MONTHLY BANKS PUMPING OF CALIFORNIA AQUEDUCT INFLOWS BY WATER YEAR TYPE

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Sampling consisted of real-time monitoring or grab sample analysis, depending on the agency, monitoring program, location, and the analyte under investigation.

Table 8
Station and Data Sampling Agency Summary

Station	Station Name	Sampling Agency
1	GREENES	State of California - DWR
2	SJRJERSEY	State of California - DWR
3	LCONNECT	State of California - DWR
4	ROCKSL	State of California - DWR
5	MIDDLER	State of California - DWR
6	BANKS	State of California - DWR
7	DMC	State of California - DWR
8	VERNALIS	State of California - DWR
9	O'NEILL	US Bureau of Reclamation
10	CHECK13	State of California - DWR
11	CHECK21	US Bureau of Reclamation
12	CROWS	CAL-EPA, RWQCB - Central Valley Region
13	EDMONSTON	State of California - DWR

Source:CALFED Bay-Delta Agricultural Water Quality Sub-Team. January 1997. Draft Report.

Data from all the respective sources were combined in an electronic database for evaluation (CALFED Agricultural Water Quality Database, 1997). Data for the parameters of concern were standardized into appropriate units of measure, and values for SAR was calculated. A summary of historical maximum, minimum, and mean values along with the corresponding date and water year type for the 13 stations is presented for each of the 13 stations in Table 9. The data identifies the range of values historically observed at each stations. These ranges can be considered in conjunction with the agricultural water quality criteria developed in this report (Table 2). The database may also serve as a tool for evaluation of water quality effects

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Table 9
Historical Water Quality Database Summary for Proposed Monitoring Stations

Parameter[a]	Units[b]	Maximum Date	Maximum Year	Year[c] Type	Maximum Result	Minimum Data	Minimum Year	Year Type	Minimum Result	Mean Result
Station: BANKS										
Boron	mg/L	03/20/95	1995	W	0.5	09/14/95	1995	W	0.1	0.2
Chloride	mg/L	02/09/89	1989	D	186.0	07/20/95	1995	W	15.0	91.0
Nutrients[d]	mg/L	01/23/92	1992	C	1.8	06/22/95	1995	W	0.0	0.7
Salinity[e]	µmol/cm	01/02/91	1991	C	877.0	07/20/95	1995	W	163.0	522.1
SAR[f]	$(mg/L)^{1/2}$	01/02/91	1991	C	4.0	08/17/95	1995	W	1.0	2.7
Turbidity	NTU	07/12/88	1988	C	33.0	04/20/94	1994	C	2.0	10.0
Station: CHECK 13										
Boron	mg/L	02/27/91	1991	C	0.3	03/17/92	1992	C	0.1	0.2
Chloride	mg/L	12/04/92	1992	C	170.0	04/24/91	1991	C	47.0	118.6
Nutrients[d]	mg/L	03/17/92	1992	C	1.4	12/04/92	1992	C	0.3	0.9
pH		12/04/92	1992	C	8.1	06/23/92	1992	C	6.9	7.6
Salinity[e]	µmol/cm	12/04/92	1992	C	972.0	03/17/92	1992	C	342.0	648.4
SAR[f]	$(mg/L)^{1/2}$	11/13/90	1990	C	3.5	04/24/91	1991	C	1.6	2.9
Turbidity	NTU	03/17/92	1992	C	19.0	07/14/92	1992	C	2.0	6.5
Station: CHECK 21										
Boron	mg/L	04/22/91	1991	C	0.2	04/22/91	1991	C	0.2	0.2
Chloride	mg/L	10/08/92	1992	C	150.0	04/22/91	1991	C	38.0	94.0
Nutrients[d]	mg/L	04/22/91	1991	C	0.9	10/08/92	1992	C	0.6	0.7
pH		12/03/92	1992	C	7.9	12/03/92	1992	C	7.9	7.9
Salinity[e]	µmol/cm	12/03/92	1992	C	835.0	10/08/92	1992	C	804.0	819.5
Turbidity	NTU	12/03/92	1992	C	10.0	12/03/92	1992	C	10.0	10.0
Station: CROWS LANDING										
Boron	mg/L	09/10/93	1993	AN	4.8	05/12/95	1995	W	0.1	1.0
Chloride	mg/L	01/25/91	1991	C	360.0	05/26/95	1995	W	14.0	187.2
pH		08/09/91	1991	C	9.7	01/15/93	1993	AN	5.90	7.9
Salinity[e]	µmol/cm	04/19/91	1991	C	2490.0	07/13/95	1995	W	143.0	1383.4
Temp	F	08/09/90	1990	C	83.0	06/27/89	1989	D	39.00	64.3
Station: DMC										
Boron	mg/L	11/19/92	1992	C	0.7	07/20/95	1995	W	0.1	0.2
Chloride	mg/L	02/09/89	1989	D	198.0	07/20/93	1993	AN	16.0	89.3
Nutrients[d]	mg/L	01/24/90	1990	C	2.2	06/22/95	1995	W	0.0	0.9
Salinity[e]	µmol/cm	02/19/88	1988	C	1200.0	07/20/93	1993	AN	180.0	565.8
SAR[f]	$(mg/L)^{1/2}$	03/11/91	1991	C	4.0	05/18/95	1995	W	1.1	2.6
Turbidity	NTU	01/26/95	1995	W	76.0	11/27/90	1990	C	3.0	13.7
Station: EDMONSTON										
Boron	mg/L	02/17/93	1993	AN	0.7	06/21/95	1995	W	0.1	0.2
Chloride	mg/L	01/18/89	1989	D	163.0	06/21/95	1995	W	15.0	92.7
Nutrients[d]	mg/L	02/15/95	1995	W	1.6	08/16/89	1989	D	0.2	0.7
pH		03/17/93	1993	AN	8.8	04/19/89	1989	D	6.9	7.9
Salinity[e]	µmol/cm	02/17/93	1993	AN	998.0	06/21/95	1995	W	160.0	584.6
SAR[f]	$(mg/L)^{1/2}$	02/17/93	1993	AN	5.7	06/21/95	1995	W	0.9	2.8
Temp	F	08/19/92	1992	C	80.2	01/18/89	1989	D	45.3	64.7
Turbidity	NTU	07/19/95	1995	W	95.5	12/13/89	1989	D	1.0	12.0

Table 9 Historical Water Quality Database Summary for Proposed Monitoring Stations										
Parameter[a]	Units[b]	Maximum Date	Maximum Year	Year[c] Type	Maximum Result	Minimum Data	Minimum Year	Year Type	Minimum Result	Mean Result
Station: GREENES										
Boron	mg/L	12/13/94	1994	C	0.2	09/22/92	1992	C	0.1	0.1
Chloride	mg/L	09/22/92	1992	C	19.0	07/25/89	1989	D	1.0	7.5
Nutrients[d]	mg/L	03/26/91	1991	C	1.7	03/23/93	1993	AN	0.0	0.6
Salinity[e]	μmol/cm	02/09/94	1994	C	253.0	03/13/86	1986	W	70.0	167.1
SAR[f]	$(mg/L)^{1/2}$	02/09/94	1994	C	0.9	03/13/86	1986	W	0.3	0.6
Turbidity	NTU	01/26/93	1993	AN	100.0	09/22/92	1992	C	1.0	12.2
Station: LCONNECT										
Boron	mg/L	01/13/93	1993	AN	0.1	01/13/93	1993	AN	0.1	0.1
Chloride	mg/L	10/20/88	1988	C	60.0	07/25/89	1989	D	4.0	16.6
Nutrients[d]	mg/L	04/23/91	1991	C	1.6	08/21/91	1991	C	0.3	0.7
Salinity[e]	μmol/cm	10/20/88	1988	C	386.0	07/08/93	1993	AN	120.0	208.6
SAR[f]	$(mg/L)^{1/2}$	07/24/91	1991	C	1.5	07/25/89	1989	D	0.6	0.9
Turbidity	NTU	01/13/93	1993	AN	38.0	01/12/94	1994	C	3.0	7.0
Station: MIDDLER										
Boron	mg/L	05/13/93	1993	AN	0.3	09/13/95	1995	W	0.1	0.1
Chloride	mg/L	12/10/92	1992	C	139.0	08/10/93	1993	AN	12.0	58.1
Nutrients[d]	mg/L	03/26/91	1991	C	1.6	07/24/91	1991	C	0.3	0.8
Salinity[e]	μmol/cm	12/10/92	1992	C	726.0	08/10/93	1993	AN	153.0	395.5
SAR[f]	$(mg/L)^{1/2}$	12/10/92	1992	C	3.2	05/17/95	1995	W	1.0	1.8
Turbidity	NTU	10/20/88	1988	C	36.0	12/11/91	1991	C	3.0	9.2
Station: O'NEILL										
Boron	mg/L	02/02/94	1994	C	0.5	01/05/94	1994	C	0.10	0.22
Chloride	mg/L	01/04/95	1995	W	150.0	06/01/94	1994	C	0.0	58.1
Nutrients[d]	mg/L	04/03/95	1995	W	0.6	06/07/95	1995	W	0.1	0.3
pH		12/07/94	1994	C	8.06	06/01/94	1994	C	6.59	7.45
Salinity[e]	μmol/cm	01/04/95	1995	W	975.0	05/04/94	1994	C	1.2	338.8
Station: ROCKSL										
Boron	mg/L	05/19/94	1994	C	0.2	10/20/94	1994	C	0.1	0.1
Chloride	mg/L	02/07/89	1989	D	303.0	07/08/93	1993	AN	12.0	117.4
Nutrients[d]	mg/L	05/23/90	1990	C	1.1	04/25/90	1990	C	0.3	0.6
Salinity[e]	μmol/cm	02/07/89	1989	D	1250.0	07/08/93	1993	AN	156.0	585.2
SAR[f]	$(mg/L)^{1/2}$	09/22/94	1994	C	5.1	07/02/86	1986	W	1.0	3.3
Turbidity	NTU	01/27/93	1993	AN	23.0	11/14/90	1990	C	2.0	8.3
Station: SJRJERSEY										
Boron	mg/L	10/07/92	1992	C	0.2	07/20/94	1994	C	0.1	0.2
Chloride	mg/L	10/23/91	1991	C	669.0	04/21/93	1993	AN	13.0	294.8
Nutrients[d]	mg/L	01/29/91	1991	C	1.4	08/22/90	1990	C	0.3	0.6
Salinity[e]	μmol/cm	10/23/91	1991	C	2500.0	04/21/93	1993	AN	185.0	1196.5
SAR[f]	$(mg/L)^{1/2}$	10/24/90	1990	C	9.2	04/20/94	1994	C	1.4	6.0
Turbidity	NTU	01/27/93	1993	AN	76.0	11/28/90	1990	C	3.0	12.1

Table 9
Historical Water Quality Database Summary for Proposed Monitoring Stations

Parameter[a]	Units[b]	Maximum Date	Maximum Year	Year[c] Type	Maximum Result	Minimum Data	Minimum Year	Year Type	Minimum Result	Mean Result
Station: VERNALIS										
Boron	mg/L	02/21/89	1989	D	1.1	10/20/94	1994	C	0.1	0.5
Chloride	mg/L	04/09/91	1991	C	221.0	04/09/86	1986	W	18.0	116.7
Nutrients[d]	mg/L	02/21/90	1990	C	3.6	05/21/91	1991	C	0.6	1.9
Salinity[e]	µmol/cm	04/09/91	1991	C	1550.0	04/09/86	1986	W	169.0	841.2
SAR[f]	$(mg/L)^{1/2}$	04/09/91	1991	C	5.5	04/09/86	1986	W	1.2	3.0
Turbidity	NTU	02/09/93	1993	AN	160.0	01/30/85	1985	D	3.0	21.6

Source: Agricultural Water Quality Database, CALFED Bay-Delta Project Agricultural Water Quality Subteam, 1997.
[a] Data for all eight parameters of concern was not available at some stations.
[b] Values from multiple data sources were normalized to presented units.
[c] Based on California DWR 40-40-30 Water Year Type Classification, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, and C = Critically Dry.
[d] Data is for nitrate nitrogen only.
[e] Data given for salinity are electrical conductivity.
[f] Sodium Adsorption Ratio.

of proposed CALFED actions. A summary of historical maximum, minimum, and mean values for each water year type at each station is presented in Table 10.

A cursory inspection of the historical water quality database summary presented in Table 8 in relation to the criteria presented in Table 2, reveals the following:

The boron average at CROWS is in the moderate range for the degree of restriction on agricultural use, with a peak value of 4.8-mg/L which is in the severe range.

- The boron ranges for all stations except CROWS were in the no on use range.

- The nutrients (nitrate nitrogen) for all stations were in the no restriction range.
- The maximum value of 3.6-mg/L is at VERNALIS. (No data was available for CROWS).
- The chloride average of 295-mg/L at SJRJERSEY (western Delta) is in the severe range for all types of irrigation. The peak value is 669-mg/L, in the severe range, with a corresponding severe-range salinity EC of 2500 -µhos/cm occurring on the same day.

- The chloride average is acceptable for sprinkle irrigation at all stations except VERNALIS, SJRJERSEY, ROCKSL, CROWS, AND CHECK13, assuming a threshold limit of 107 mg/L of chloride.

- The maximum salinity of approximately 2500 µmhos/cm which is in the severe restriction on use range was recorded at both CROWS and SJRJERSEY. This extreme value was measured at both stations in the same year, 1991, which was a C water year (critically dry year), followed by a C water year in 1992 [check this with George].

- The average salinity at CROWS, VERNALIS, and SJRJERSEY was in the moderate range, and the average for BANKS, CHECK13, CHECK21, DMC, EDMONSTON, and ROCKSL was in the slight range for restrictions on use.

These initial cursory observations illustrate the relationship between the use and benefit of historical water quality and proposed agricultural water quality criteria. In many cases, water quality is not ideal. The intended use of the criteria was presented in the introduction. In general, it is recognized that they do not describe agricultural water quality as it always is or always will be, but rather provide a benchmark of favorable water quality for agricultural supply. More extensive development and use of this database during the CALFED process is anticipated. For the moment, data anomalies remain in the CROWS and O'NEILL data sets.

Evaluation

Crop and cropland needs were identified as the principal means of defining favorable agricultural water quality. The existence of several excellent data resources provided a sound

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Table 10
Historical Water Quality Database Summary for Proposed Monitoring Stations by Water Year Type

Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Station: BANKS					
Boron	mg/L	A	0.3	0.1	0.2
	mg/L	C	0.4	0.1	0.2
	mg/L	D	0.1	0.1	0.1
	mg/L	W	0.5	0.1	0.2
Chloride	mg/L	A	81.0	16.0	46.6
	mg/L	C	185.0	34.0	105.8
	mg/L	D	186.0	20.0	84.8
	mg/L	W	79.0	15.0	36.3
Nutrients[d]	mg/L	C	1.8	0.3	0.8
	mg/L	W	0.1	0.0	0.1
Salinity[e]	µmhos/cm	A	490.0	174.0	363.6
	µmhos/cm	C	877.0	309.0	578.9
	µmhos/cm	D	863.0	221.0	492.9
	µmhos/cm	W	488.0	163.0	309.0
SAR[f]	$(mg/L)^{1/2}$	C	4.0	1.4	2.9
		D	3.2	1.9	2.6
		W	2.3	1.0	1.4
Turbidity	NTU	A	27.0	3.0	10.9
	NTU	C	33.0	2.0	8.8
	NTU	D	32.0	6.0	12.6
	NTU	W	32.0	3.0	14.1
Station: CHECK 13					
Boron	mg/L	C	0.3	0.1	0.2
Chloride	mg/L	C	170.0	47.0	118.6
Nutrients[d]	mg/L	C	1.4	0.3	0.9
pH		C	8.1	6.9	7.6
Salinity[e]	µmhos/cm	C	972.0	342.0	648.4
SAR[f]		C	3.5	1.6	2.9
Turbidity	NTU	C	19.0	2.0	6.5
Station: CHECK 21					
Boron	mg/L	C	0.2	0.2	0.2
Chloride	mg/L	C	150.0	38.0	94.0
Nutrients[d]	mg/L	C	0.9	0.6	0.7
pH		C	7.9	5.9	7.9
Salinity[e]	µmhos/cm	C	835.0	804.0	819.5
Turbidity	NTU	C	10.0	10.0	10.0
Station: CROWS LANDING					
Boron	mg/L	A	4.8	0.1	0.8
	mg/L	C	2.1	0.2	1.1
	mg/L	D	1.9	0.3	1.1
	mg/L	W	1.7	0.1	0.5

Table 10 Historical Water Quality Database Summary for Proposed Monitoring Stations by Water Year Type					
Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Chloride	mg/L	A	246.0	79.8	128.5
	mg/L	C	360.0	86.1	211.3
	mg/L	D	280.0	77.0	191.0
	mg/L	W	290.0	14.0	82.8
pH		A	9.3	6.9	7.978
		C	9.7	5.9	8.0
		D	8.9	6.6	7.7
		W	8.6	6.9	7.9
Salinity[e]	µmhos/cm	A	1940.0	209.0	959.2
	µmhos/cm	C	2490.0	560.0	1566.8
	µmhos/cm	D	2210.0	630.0	1453.4
	µmhos/cm	W	2060.0	143.0	675.3
Temp	F	A	81.0	44.0	66.0
	F	C	83.0	39.0	64.1
	F	D	83.0	41.0	63.854
	F	W	82.0	49.7	66.0
Station: DMC					
Boron	mg/L	A	0.4	0.1	0.2
	mg/L	C	0.7	0.1	0.3
	mg/L	D	0.1	0.1	0.1
	mg/L	W	0.4	0.1	0.2
Chloride	mg/L	A	111.0	16.0	52.3
	mg/L	C	181.0	32.0	104.6
	mg/L	D	198.0	18.0	77.0
	mg/L	W	74.0	18.0	43.8
Nutrients[d]	mg/L	C	2.2	0.3	1.0
	mg/L	W	0.2	0.0	0.1
Salinity[e]	µmhos/cm	A	775.0	180.0	422.2
	µmhos/cm	C	1200.0	306.0	634.5
	µmhos/cm	D	897.0	209.0	493.7
	µmhos/cm	W	643.0	191.0	375.0
SAR[f]	$(mg/L)^{1/2}$	C	4.0	1.6	2.8
		D	3.6	2.6	3.1
		W	2.5	1.1	1.7
Turbidity	NTU	A	30.0	6.0	16.5
	NTU	C	28.0	3.0	12.1
	NTU	D	24.0	7.0	13.0
	NTU	W	76.0	8.0	22.2

Table 10
Historical Water Quality Database Summary for Proposed Monitoring Stations by Water Year Type

Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Station: EDMONSTON					
Boron	mg/L	AN	0.7	0.1	0.3
	mg/L	C	0.4	0.1	0.3
	mg/L	D	0.3	0.1	0.2
	mg/L	W	0.4	0.1	0.2
Chloride	mg/L	AN	154.0	24.0	80.1
	mg/L	C	145.0	60.0	106.5
	mg/L	D	163.0	36.0	102.4
	mg/L	W	97.0	15.0	45.9
Nutrients[d]	mg/L	AN	1.5	0.2	0.7
	mg/L	C	1.5	0.2	0.7
	mg/L	D	1.5	0.2	0.8
	mg/L	W	1.6	0.3	0.7
pH		AN	8.8	7.2	8.0
		C	8.5	7.2	7.9
		D	8.0	6.9	7.7
		W	8.3	7.8	8.0
Salinity[e]	µmhos/cm	AN	998.0	238.0	534.5
	µmhos/cm	C	848.0	414.0	663.9
	µmhos/cm	D	815.0	286.0	552.7
	µmhos/cm	W	684.0	160.0	375.0
SAR[f]	$(mg/L)^{1/2}$	AN	5.7	1.4	2.7
		C	4.2	1.9	3.1
		D	3.5	1.4	2.7
		W	3.4	0.9	1.8
Temp	F	AN	76.3	48.7	65.2
	F	C	80.2	47.3	64.9
	F	D	79.3	45.3	63.7
	F	W	76.3	50.9	64.6
Turbidity	NTU	AN	21.8	2.6	14.3
	NTU	C	17.7	1.7	6.6
	NTU	D	13.0	1.0	6.2
	NTU	W	95.5	3.3	25.8
Station: GREENES					
Boron	mg/L	C	0.2	0.1	0.1
	mg/L	D	0.1	0.1	0.1
	mg/L	W	0.1	0.1	0.1
Chloride	mg/L	A	11.0	3.0	5.6
	mg/L	C	19.0	5.0	8.9
	mg/L	D	9.0	1.0	6.4
	mg/L	W	10.0	2.0	4.9

Table 10
Historical Water Quality Database Summary for Proposed Monitoring Stations by Water Year Type

Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Nutrients[d]	mg/L	A	0.0	0.0	0.0
	mg/L	C	1.7	0.1	0.7
Salinity[e]	µmhos/cm	A	227.0	105.0	138.6
	µmhos/cm	C	253.0	128.0	183.4
	µmhos/cm	D	207.0	110.0	162.8
	µmhos/cm	W	218.0	70.0	131.2
SAR[f]	$(mg/L)^{1/2}$	C	0.9	0.4	0.7
		D	0.8	0.4	0.6
		W	0.7	0.3	0.5
Turbidity	NTU	A	100.0	2.0	17.8
	NTU	C	72.0	1.0	8.7
	NTU	D	70.0	3.0	10.5
	NTU	W	72.0	7.0	26.1
Station: LCONNECT					
Boron	mg/L	A	0.1	0.1	0.1
	mg/L	C	0.1	0.1	0.1
Chloride	mg/L	A	23.0	8.0	12.6
	mg/L	C	60.0	9.0	19.4
	mg/L	D	22.0	4.0	12.3
	mg/L	W	37.0	8.0	14.8
Nutrients[d]	mg/L	C	1.6	0.3	0.7
Salinity[e]	µmhos/cm	A	247.0	120.0	165.0
	µmhos/cm	C	386.0	160.0	226.9
	µmhos/cm	D	258.0	130.0	193.3
	µmhos/cm	W	281.0	136.0	177.8
SAR[f]	$(mg/L)^{1/2}$	C	1.5	0.6	1.0
		D	0.6	0.6	0.6
Turbidity	NTU	A	38.0	4.0	11.4
	NTU	C	18.0	3.0	6.4
	NTU	D	10.0	4.0	5.6
	NTU	W	22.0	5.0	10.7
Station: MIDDLER					
Boron	mg/L	A	0.3	0.1	0.2
	mg/L	C	0.2	0.1	0.1
	mg/L	D	0.1	0.1	0.1
	mg/L	W	0.2	0.1	0.1
Chloride	mg/L	A	68.0	12.0	40.9
	mg/L	C	139.0	27.0	74.8
	mg/L	D	83.0	16.0	42.1
	mg/L	W	64.0	15.0	28.0
Nutrients[d]	mg/L	C	1.6	0.3	0.8

Table 10
Historical Water Quality Database Summary for
Proposed Monitoring Stations by Water Year Type

Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Salinity[e]	µmhos/cm	A	520.0	153.0	333.3
	µmhos/cm	C	726.0	286.0	465.9
	µmhos/cm	D	469.0	199.0	327.6
	µmhos/cm	W	472.0	165.0	260.9
SAR[f]	$(mg/L)^{1/2}$	C	3.2	1.1	2.1
		D	2.0	1.1	1.4
		W	1.8	1.0	1.2
Turbidity	NTU	A	20.0	5.0	8.8
	NTU	C	36.0	3.0	8.1
	NTU	D	17.0	5.0	10.1
	NTU	W	24.0	6.0	13.5
Station: O'NEILL					
Boron	mg/L	C	0.2	0.1	0.16
	mg/L	W	0.5	0.1	0.3
Chloride	mg/L	C	110.0	0.0	69.5
	mg/L	W	150.0	13.0	50.9
Nutrients[d]	mg/L	W	0.6	0.1	0.3
pH		C	8.06	7.35	7.706
		W	7.7	6.6	7.2
Salinity[e]	µmhos/cm	C	333.0	1.2	84.3
	umhos/cm	W	975.0	149.0	357.9
Station: ROCKSL					
Boron	mg/L	C	0.2	0.1	0.1
	mg/L	W	0.2	0.1	0.2
Chloride	mg/L	A	80.0	12.0	30.3
	mg/L	C	277.0	28.0	136.7
	mg/L	D	303.0	18.0	103.2
	mg/L	W	85.0	14.0	33.1
Nutrients[d]	mg/L	C	1.1	0.3	0.6
Salinity[e]	µmhos/cm	A	425.0	156.0	263.0
	µmhos/cm	C	1140.0	268.0	657.2
	µmhos/cm	D	1250.0	194.0	532.0
	µmhos/cm	W	476.0	180.0	271.0
SAR[f]	$(mg/L)^{1/2}$	C	5.1	1.2	3.4
		W	2.4	1.0	1.7
Turbidity	NTU	A	23.0	4.0	9.8
	NTU	C	21.0	2.0	7.2
	NTU	D	19.0	3.0	9.2
	NTU	W	22.0	6.0	15.0
Station: SJRJERSEY					
Boron	mg/L	A	0.1	0.1	0.1
	mg/L	C	0.2	0.1	0.2
Chloride	mg/L	A	174.0	13.0	67.0
	mg/L	C	669.0	39.0	328.8
Nutrients[d]	mg/L	C	1.4	0.3	0.6
Salinity[e]	µmhos/cm	A	727.0	185.0	382.8
	µmhos/cm	C	2500.0	331.0	1317.9
SAR[f]	$(mg/L)^{1/2}$	C	9.2	1.4	6.0
Turbidity	NTU	A	76.0	10.0	26.2
	NTU	C	18.0	3.0	10.0

Table 10
Historical Water Quality Database Summary for Proposed Monitoring Stations by Water Year Type

Parameters[a]	Units[b]	Year[c] Type	Maximum Result	Minimum Result	Mean Result
Station: VERNALIS					
Boron	mg/L	A	0.9	0.1	0.4
	mg/L	C	1.0	0.1	0.5
	mg/L	D	1.1	0.4	0.6
	mg/L	W	0.4	0.1	0.2
Chloride	mg/L	A	161.0	20.0	80.4
	mg/L	C	221.0	38.0	128.0
	mg/L	D	206.0	55.0	117.9
	mg/L	W	107.0	18.0	50.9
Nutrients[d]	mg/L	C	3.6	0.6	1.9
Salinity[e]	µmhos/cm	A	1180.0	195.0	632.5
	µmhos/cm	C	1550.0	317.0	898.6
	µmhos/cm	D	1460.0	483.0	878.9
	µmhos/cm	W	790.0	169.0	424.6
SAR[f]	$(mg/L)^{1/2}$	C	5.5	1.8	3.2
		D	4.4	2.4	3.2
		W	2.4	1.2	1.7
Turbidity	NTU	A	160.0	10.0	32.4
	NTU	C	68.0	4.0	19.9
	NTU	D	52.0	3.0	21.5
	NTU	W	26.0	9.0	17.5

Source: Agricultural Water Quality Database, CALFED Bay-Delta Project Agricultural Water Quality Subteam, 1997.

[a] Data for all eight parameters of concern was not available at some stations.

[b] Values from multiple data sources were normalized to presented units.

[c] Based on California DWR 40-40-30 Water Year Type Classification, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, and C = Critically Dry.

[d] Data is for nitrate nitrogen only.

[e] Data given for salinity are electrical conductivity.

[f] Sodium Adsorption Ratio.

basis for development of meaningful water quality criteria for use as an analysis tool during the CALFED process. These data resources include the following:

- In general, crop and farmland sensitivity to irrigation water quality has received substantial research attention in California.

- Agricultural land use, including acreages of the many crops cultivated in the state, has been monitored and reported every 5 years.

- Interrelationships of agricultural water quality with crop yields, drainage water quality and quantity, soil conditions, and costs of reclamation have been defined in a number of studies.

- Substantial effort has been invested in sampling water quality throughout California, and in compiling these data in electronic databases.

The subteam's approach consisted of identifying and documenting relevant water quality parameters for agricultural water supply, identifying their linkages with land and water management, defining temporal and geographic relationships of the parameters, definition of favorable ranges (or criteria) for each parameter, and compilation of existing data for parameters at key locations in the Delta and related water distribution systems. This approach appeared to provide a reasonable, if general definition of water quality for agriculture.

Water quality criteria developed by the subteam are not intended for regulatory application. Rather, they are analytical tools for the CALFED process. CALFED goals and solution principles suggest that actions may improve irrigation water quality in parts of the Delta, and should not result in significant degradation of water quality in export areas. To help guide such an effort, the CALFED process must have a working definition of what good agricultural water quality is. Clearly, such criteria are not, and will not be achievable at all times and places in the water distribution system. For example, data presented in this report illustrate that water not meeting the specified criteria is currently delivered to many farms. While actions associated with CALFED may result in some improvement, they cannot address each of these agricultural water quality challenges in their entirety.

Parameters of concern to agriculture are those potentially influencing plant growth, harvested crop quality, soil conditions, and irrigation facilities. They include salinity, nutrients, specific ions, acidity, turbidity, and temperature. Sensitivity to each parameter varies among crops and time of year. In general, the most sensitive crops irrigated with water from the Delta were considered when developing favorable ranges for parameters. Although fields containing less sensitive crops might tolerate water of lesser quality, distribution systems generally do not allow delivery of one type of water to one field, and another type to another field, within the same locale. Also, cropping patterns tend to be determined by market forces and field conditions, and it is considered an extreme measure to alter cropping patterns due to water quality.

The timing and location of water quality criteria application depend on the relationship of water quality at a particular time and place to the quality of delivered agricultural water. In large parts of areas served with water drawn from the Delta, the growing season occupies most of the year's calendar. Further, export to reservoirs such as San Luis occurs nearly year-round, even though most of the irrigation water is delivered during the peak growing season. Therefore, it is desirable that water at the export pumps nearly always meet agricultural water quality criteria.

Regarding agricultural water quality as it relates to CALFED, the following is anticipated:

- Agricultural water quality needs will form part of the basis for evaluation of actions that CALFED will consider to address various environmental and water supply issues in and related to the Delta.

- Agricultural supply water quality criteria developed in this report will provide at least a general definition of the needs of agricultural users. More specific definitions will be developed as needed throughout the process.

- The water quality database that was compiled for this report, which contains information for a number of parameters and stations that were not utilized in this analysis, may be a useful tool for evaluating historical water quality in and around the Delta, as it relates to various environmental needs and actions that CALFED may need to study. Expansion of the database to include still more stations and parameters is feasible, and should be more efficient for many purposes of CALFED water quality studies than working with other electronic or hardcopy data resources, since parameter names and units have already been standardized among stations within the database.

The subteam's input relative to CALFED action's impact on water quality was not discussed in this report. Rather, the actions are presented and discussed in some detail in the report of the CALFED Water Quality Technical Group, into which the subteam's membership was incorporated after the subteam's dissolution. The subteam's understanding of and commentary on the actions was incorporated in this later work.

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